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CANADIAN SOLAR ENERGY REVIEW - MARCH 1986

by

J.P. Rollefson
Solar Energy Program
Division of Energy
National Research Council

MAY 1986

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ABSTRACT

This document gives some of the highlights of the progress made recently in the development of technologies to exploit solar energy in Canada. It includes a brief discussion of the solar resource itself. Active, passive solar, and photovoltaics developments are explained in separate chapters. An economic perspective of the technologies is given in the light of the Canadian situation. Of the three solar options, passive solar, understood in the wide sense of superior window technology and efficient energy management of buildings, is concluded to have the greatest potential impact on Canada's energy demand in the near and medium term.

CANADIAN SOLAR ENERGY REVIEW - MARCH 1986

J.P. Rollefson

1. INTRODUCTION

Stimulated by the oil crisis of 1973-74 many of the industrialized countries devoted important resources to the development of solar energy. The United States were quickly off the mark with a substantial R&D program and tax credits. This generated a spectacular upsurge in business related to solar, especially active solar technology. Canada was faced with a pressing decision: should it create its own solar industry or rely on and import American technology.

In 1978 the Canadian Government decided to create an indigenous industry. It announced the creation of the Program of Assistance to Solar Equipment Manufacturers (PASEM), the Program for the Purchase and Use of Solar Heating (PUSH), and an accelerated R&D program to be coordinated by the Solar Energy Project of NRC. PASEM was to help ten selected companies to develop the industrial capability to produce active solar products. PUSH was to provide the early market for the products with possible funding of $125 000 000 over five years. The policy of government procurement rather than incentives was to have the collectivity assume the high risk of failure associated with the premature technology. Thus, the Canadian policy in solar was from the beginning heavily influenced by the American situation and by the desire to acquire the "maximum industrial advantages" noted in the general energy policy statement of 1975.

After a full review, it was decided in 1983 to phase out PUSH. While the program had been successful in generating some private sector interest in producing solar equipment, justification was never found for spending the first-announced funding. Also, by 1983 the reliability of solar technology had improved to the point that demonstration programs to encourage the Canadian public and commercial interests to buy active solar products were appropriate. The government set forth a new plan with a principal objective to make the Canadian solar industry self-supporting with cost-effective products in five years. $79,000,000 was the budget in R&D and in demonstrations accorded for the task.

However, in November of 1984 the newly-elected Government decided that cost reduction measures throughout all sectors were imperative. The Solar Energy Program of the National Research Council (NRC) was to be phased out and reductions made in funds available through the Department of Energy, Mines and Resources (EMR). There has since been a rationalization of the solar industry. One positive aspect of this fact is that the demonstration program can provide a significant market to the remaining firms.

The Canadian technology now is in many respects on a par or superior to products available internationally. Some industrial advantages, mainly through export sales to the United States, can be realistically envisaged. However, it is anticipated that active solar will not play any major role in energy displacement in Canada before the year 2000.

As this introduction suggests, active solar technology has dominated the funding and priorities of government solar efforts up until now. Nevertheless, the progress made in the passive solar R&D program has been substantial. Further R&D in the most promising areas identified by the passive program can lead to a significant impact on conventional energy consumption in Canada. The Canadian photovoltaics (PV) R&D program has been small in comparison with national programs in the United States, Japan, and Europe. From the modest base of Canadian PV research we can only expect to play a limited role in future PV development.

The three solar technologies of active, passive, and photovoltaics have distinct attributes and applications and have evolved very differently. The following sections will therefore analyze separately these three technologies. However, first a brief overview of the solar resource in Canada will be given.

2. THE CANADIAN SOLAR RESOURCE

To understand why solar energy can at the same time be free and yet difficult to make cost effective, it is necessary to appreciate the nature of the solar resource. Solar energy is dilute. In Canada it takes 3 d of average solar radiation on a surface of 1 m^2 to yield the energy equivalent of 1 L of oil. Solar energy is intermittent. Either it can be used as an adjunct to the principal source of energy or substantial energy storage capacity is needed. The winter season combines lower solar intensities and temperatures to make it more difficult to collect efficiently the solar energy.

Yet the solar resource in Canada is not to be neglected. The annual global irradiance ranges from 5.2 GJ/(m^2·a) in Lethbridge to 4.6 GJ/(m^2·a) in Toronto to 4.0 GJ/(m^2·a) in St. John's. These values are comparable to those of Europe and the northern United States. A collector area of 4-5 m^2 is sufficient to supply half the hot water needs of a typical family in Canada. The solar radiation through windows can readily supply 20-25% of the space heating needs of a house.

2.1 The State of Canadian Solar Resource Assessment

The system for the assessment of the solar resource in Canada is one of the most advanced in the world. Direct observations of horizontal radiation data are made over a network of 50 stations across the country. A model, MAC.3, has been developed and used to estimate hourly global irradiance and its direct and diffuse components to expand the data set to 129 locations. Techniques have been developed to convert the information on direct and diffuse radiation plus that on ground reflections into radiation values for inclined surfaces.

The observed or estimated data have been put into formats that are usable for a wide variety of purposes. In particular, the hourly data of solar radiation, temperature, and wind speed over a period of 10 a are available on nine-track magnetic tape. The hourly measured values of global radiation have been shown to be accurate to 5% with averaging processes reducing the bias error to 2.5%. As the pyranometers are only accurate to 2% this gives an indication that it would be difficult to improve further the quality of data. Comparison of measured data with values estimated from the models indicates that the mean bias errors of derived quantities are generally less than 10%. As it is, the radiation data accuracy is entirely adequate for solar performance evaluation.

Through the International Energy Agency, the Atmospheric Environment Service is ensuring that its knowledge of modelling and of instrumentation, especially of pyranometers, contributes to other national efforts, while AES keeps abreast of the most recent developments elsewhere.

3. ACTIVE SOLAR

3.1 International Perspective in Active Solar

An active system has discrete units for the collection, distribution, and storage of energy and uses auxiliary power and controls to transfer heat to the load as needed. The control features makes an active system compatible as an add-on to conventional heating systems. This compatibility with existing equipment and the impression that active solar was a simple extension of available heating and cooling technology made active solar the early focus of many of the national programs. Moreover, countries like Israel and Mexico already had good commercial activity in the field before the emergence of world interest in the middle seventies.

An underestimation of the rigours of the operating conditions under which solar systems must operate led to early problems in reliability and durability in most of the accelerated development programs. Especially difficult was ensuring the freeze protection of systems at a reasonable cost. A simple thermosyphon system can still be one-quarter to one-half the cost of a fully freeze-protected drain-back system.

Now the problems of reliability and durability have largely been surmounted (although in the United States there remain real problems with some dealers installing poor or totally inoperative systems). Research efforts are directed towards improving cost effectiveness through simplifications to systems design and also through the development of materials that are less costly and lend themselves to economies of scale for large production.

The type and performance of active solar systems are very dependent on the application. Swimming pool collector systems can be extremely simple as they are designed to heat water only slightly above ambient and are to be drained during freezing weather. The next system in line of complexity is the solar domestic hot water system for a moderate climate without danger of frost. In these favourable climates outputs of 3 GJ/(m^2•a) are realized. Small systems for commercial applications can work well using the thermosyphon principle but as larger sizes are sought a forced pumping system becomes more practical. Output is inversely proportional to the temperature sought; 4 GJ/(m^2•a) is possible for very low temperature preheat while 2 GJ/(m^2•a) is good for temperatures approaching 80-90°C. For the solar domestic hot water (DHW) and commercial/industrial process heat (CIPH) systems to achieve good performance they must be properly sized for the load and the load should be year round.

For climates with just occasional frost the thermosyphon system can be adapted to serve well. Figure 1 shows a schematic of one of these systems. Several factors enhance the economic viability of this design. The

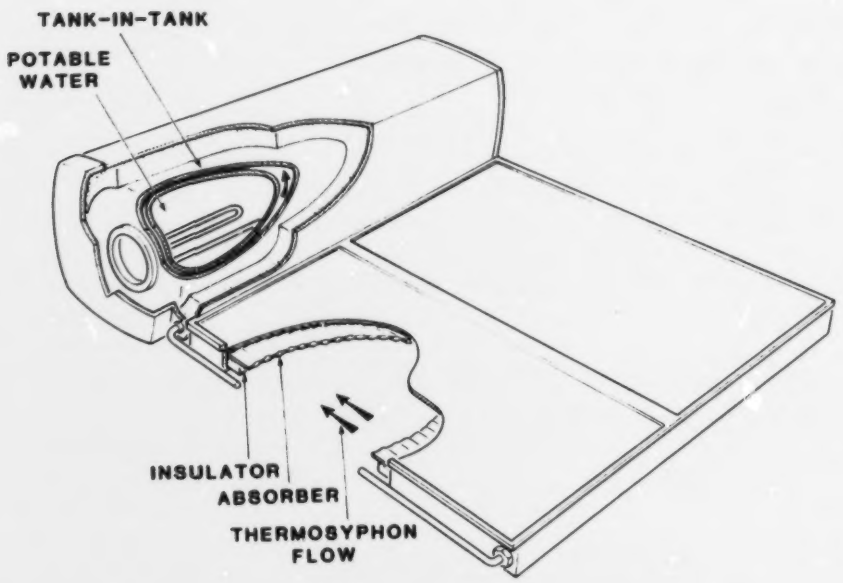


Figure 1. A freeze-protected solar thermosyphon system (loosely derived from the Solahart 300LJ system).

thermosyphon flow itself necessitates no controls. The thermal mass of the storage tank requires considerable time before the water in it would freeze or overheat. (An electric heater provides additional protection for long periods of cold weather.) Because the thermal mass counteracts undesirable high temperatures and pressure of the circulating fluid in the thermosyphon flow it is possible to control tightly the non-corrosive properties of the fluid and thus use much cheaper materials in the absorber (in this case, ordinary steel). The system connects directly to the pressurized hot water system, thus eliminating pumps, secondary heat exchangers, and the like.

The thermosyphon solar DHW system is certainly among the most cost effective options where the climate permits its use. Units similar to that of Figure 1 can retail for about $1300 in Australia. In Japan sales of thermosyphon units are presently 500 000/a at a retail price installed of $850.[1]

The next step in complexity is the drain-down solar DHW system widely used in the late seventies in the United States. When no solar gains are to be made this system isolates the mains pressure from the collector by activating a solenoid valve. This allows the water to flow out of the collectors to the drain. The reliability of the solenoid valve has, however, been a

[1] Unless explicitly expressed otherwise, all money is in Canadian dollars.

very serious problem. While there appears to have been good progress in developing more reliable drain-down valves, the degree of damage that can result from just one valve failure over the life of the solar system still mitigates against this approach, expecially in climates like that of Canada.

The next step in freeze protection is to isolate the solar collector loop from the potable water supply by using either a closed-loop antifreeze system or a drain-back system. The antifreeze solution is still widely applicable to large systems in commercial and industrial sites where some on-going maintenance can be guaranteed. However, the maintenance required for the antifreeze closed-loop DHW system appears to be beyond that to be expected of the average homeowner. With one visit by a qualified trades-person costing almost as much as the annual savings realized by the system it is clear why this type of DHW unit is waning in popularity.

A type of system making some progress in the northern climates is the refrigerant-charged unit. Freeze protection is provided simply by not using any water in the outside piping. Typically the collector acts as an evaporator and the heat is transferred to the storage tank using a condenser. While most of these systems use an external energy supply to pump the condensed liquid back to the collectors the possibility does exist to use part of the solar energy available to drive the flow independent of any external source. Besides the guaranteed freeze protection these systems offer the advantages of permitting the use of aluminum only in the absorber and of small flexible piping between collector and storage. On the negative side is the great care that must be taken in installation to have the system totally leak-free and purged of non-condensible gases.

The seasonal variations of solar availability and temperature at latitudes typical of Canada not only affect freeze-protection measures, they impact on the performance and the optimum solar fraction to be sought from a system. A very low-temperature application for preheating industrial water can still lead to a 3 GJ/(m^2•a) output in the Canadian climate, whereas good solar DHW systems give 1.5-2 GJ/(m^2•a) when properly sized. The solar DHW system should be large enough to meet about 50% of the load because of the substantial fixed cost component associated with this size of unit. However, beyond about a 65% solar fraction the extra collector area is only being fully used in winter. The diminishing returns are directly reflected in a reduced solar output per unit area.

The incremental costs associated with full freeze protection are very important. Typical costs in the United States for one of these solar DHW systems is $3000-$4000 (U.S.$) while in Canada they are about $3000 for a 4-5 m^2 system. A full breakdown of cost will be given in the section on economics to explain the reasons behind this.

The use of active solar technology for space heating runs into the obvious problem that there is a bad mismatch between the solar availability and its need for heating. The choice becomes to put in a very low cost system giving a small solar fraction or to use seasonal storage. Research efforts to develop economic methods of storing energy seasonally in order to use the sun's summer energy in the winter have been shown to be economically feasible in only very limited areas like parts of Sweden. Here some district heating networks allow one to consider very large underground storage systems. Very large sizes are more economical because heat losses increase as the dimension squared while heat stored augments as the dimension cubed.

Active liquid solar systems for space heating are just too expensive to attract much attention with short-term storage but some active solar air systems are still being installed in the United States for residential space heating. However, in Canada virtually no systems of this kind are being installed in residences following the rather conclusive studies of the National Research Council showing it as as an uneconomic proposition. Not only is the energy output low, about 1 $GJ/(m^2 \cdot a)$, but the air handling proves to be very problematic. This is because it takes about 3440 times more volume flow of air as compared to water to transfer the same amount of energy given the same temperature difference. Thus, air ducts tend to be large and difficult to insulate and keep hermetic at a low cost.

Solar air collectors can be less materials intensive than liquid ones so the costs for the collection itself can be kept low. If the distribution system can be kept extremely simple then some case can be made for the use of air. For instance, a simple solar air wall system is well suited to the preheating of ventilation air for large interior spaces. In tropical climates, a solar air system for crop drying may be interesting if there is a substantial part of the year when it is needed.

To achieve high temperatures output from solar systems some form of concentration is typically used. This is because, even if collection can be reasonably efficient using evacuated tube collectors, losses from high temperature distribution piping quickly become very important. Therefore single-axis tracking with parabolic reflecting systems is a first step to temperatures of 80-120°C, while temperatures needed for electrical power generation require tracking reflectors (heliostats) that focus light onto a central receiver. As these concentrating systems can only use the direct and not the diffuse component of radiation their use is restricted for practical purposes to desert areas. Progress has recently been made in designing much cheaper heliostats using thin-film polymers but even this progress is not likely to give much commercial impetus to this avenue of development. The operating costs alone for the large French central receiver outweigh the revenues generated by the electricity.

In summary, the most mature aspect of the active solar industry is for domestic hot water heating with concentration of activity in a few countries. They include Israel, Australia, Japan, Mexico, and the United States. In Japan, low-interest loans (5.5%, 5 years for residences; 6.5%, 10 years for commerce) are the chief factor in promoting sales because, even with domestic electricity prices of 0.084,$/kWh, solar system prices are considered too high by a factor of two to be attractive unaided. In the United States, generous tax credits have been extremely important in generating active solar sales approaching 1 000 000 000 $/a. Canadian production of solar collectors was 77 000 m^2 in 1983 and was anticipated to grow to 85 000-95 000 m^2 in 1984, this being some 6% of American production of 1 500 000 m^2 for the same year.

Because of the scale of its commercial activity the American active solar market is of prime interest on the world scene in the near term. It now appears that that the American tax credits will be phased out over the next three years. One can expect a very significant shakedown in the American industry. Some of the less efficient, more costly products should decline sharply in sales and more advanced technologies should gain a larger share of the much more restricted market.

3.2 Canadian Accomplishments in Active Solar

3.2.1 Simulation Programs

The solar resource data indicate what energy is available from the sun. Simulation programs indicate how much energy can be expected to be delivered and used. Considerable effort has been expended on perfecting these simulation tools because:

(a) they indicate performance levels attainable for different applications
(b) they permit sensitivity analysis of the effects of different components on overall performance, thus helping to design systems or identify priorities for R&D to improve them

The principal set of simulation programs for active solar in Canada is WATSUN developed at the University of Waterloo. The applications to which the different programs apply are industrial or commercial process heating, pool heating, and solar domestic hot water. A number of subroutines are available to simulate most kinds of systems. For instance, options to simulate tank-in-tank, immersed coil, wrap-around, or external heat exchangers are available. The storage tank model can be chosen to be fully mixed or stratified. Pipe losses and some heat capacity effects can be taken into account. The latest and most accurate collector characteriza-

tion model, especially valuable for evacuated tube or boiling/condensing units, has been incorporated into WATSUN.

A number of experiments to validate WATSUN have shown it to be accurate to 5-15%. Any errors larger than this can almost always be attributed to improper designation of system parameters, system malfunction, or observed problems like snow accumulation on collectors.

The major limitation to WATSUN is that it is not suitable to simulate any transient effects (thus limiting any control studies) as its logic works on a quasi-steady-state hypothesis using hourly-averaged meteorological and load data. In specific (but rare) occasions this has been shown not to be appropriate and small time steps have been needed to give good overall system characterization.

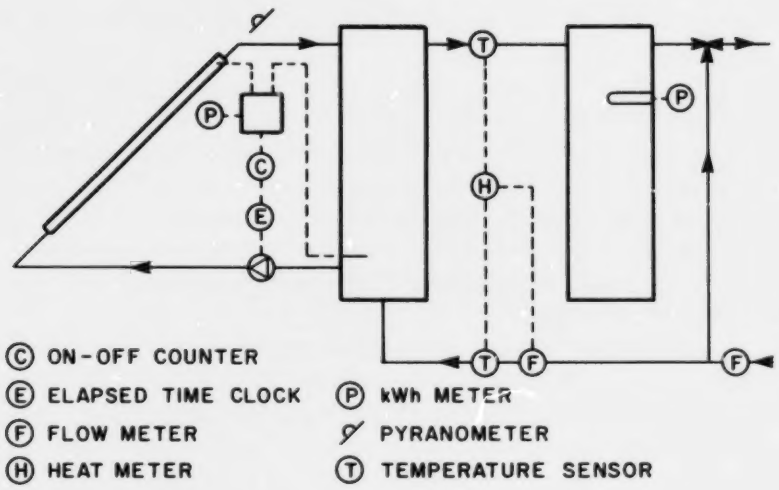
WATSUN is user friendly and gives simulation results as opposed to correlative approximations. In most instances, it gives similar results to TRNSYS so the latter need only be used when special subcomponents or transients are important to the performance study. WATSUN can be accessed through a user service located at the University of Waterloo. A micro-computer version is available along with a file of typical meteorological years for 31 Canadian sites and 36 sites in the United States.

Syphon, another simulation program available from the WATSUN user service, has been derived particularly for thermosyphon systems. Through comparison with test results it has been shown to give good estimations of thermosyphon performance although, as used presently, it tends to overestimate by some 5-15%.

3.2.2 Monitoring Techniques

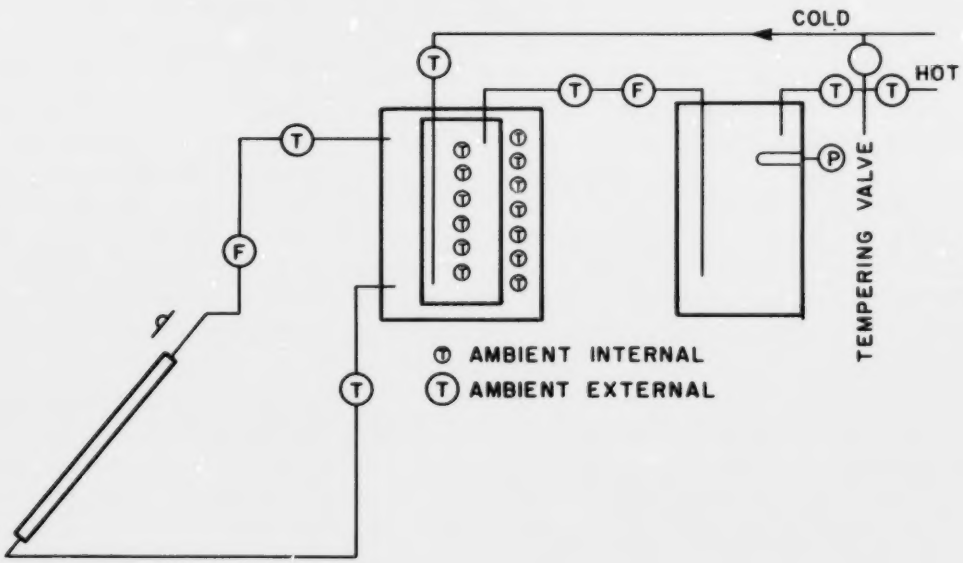
For solar domestic hot water systems over two years of monitoring have been undertaken to compare a variety of systems at the Solar DHW Test Facility at NRC. Average daily values of radiation, solar energy collected, and auxiliary energy have been tabulated and used to improve the simulation by WATSUN as well as identify promising system designs. The data have also been used to compare actual year-round performance with a "standard-day" test proposed in the CSA's F379.1 as a good indicator of overall performance. Initial results are encouraging with projected performance levels within 10% of actual values.

The latest monitoring (see Figures 2 and 3 for comparison of this and the earlier methodology) at the test facility has been at a higher level with a finer time scale of measurement and with a series of temperature probes inserted in the storage tank to describe better the characteristics of the



DAILY INTEGRATED VALUES RETAINED FOR ANALYSIS

Figure 2. Schematic of monitoring in first phase of testing of solar DHW systems (after Fig. 3, S.B. Beale and B.E. Sibbitt, "Monitoring of Solar Domestic Hot Water Systems at the National Research Council of Canada," Proceedings of Intersol '85, June 1985).



VALUES AT 1-min INTERVALS RETAINED FOR ANALYSIS

Figure 3. Schematic of latest monitoring of solar DHW systems.

stored energy. This more advanced monitoring allows much quicker assessment of critical factors affecting performance. Once the system features are well characterized using this method simulations permit good estimation of yearly performance.

For commercial and industrial applications, a number of high-level monitoring projects in the field have identified specific problems (e.g., fouled heat exchangers, etc.) and increased our knowledge of the relative importance of some system effects. This knowledge has in turn been transferred into the simulation programs.

One aspect of field monitoring remains important. Load characteristics given in design studies for CIPH applications have far too often proven to be significantly in error. As the system design and performance depend critically on this load data, monitoring of the actual load should precede the solar installation.

Following a thorough commissioning, most systems in the field should now require only an integrated heat meter. However, innovative concepts in initial field trials could profit from a recently developed commissioning package that allows immediate comparison of actual and simulated results on site.

In conclusion, solar monitoring techniques have advanced considerably in the past few years. Reliable equipment and good methodology have been identified. The high-level monitoring and subsequent data analysis in the field have proven very expensive (e.g., that done as Canada's contribution to Task VI of IEA's Solar Heating and Cooling Program has cost about $1 000 000) and need not be repeated. Information from the monitoring projects has been used to improve the simulation program, WATSUN. For DHW systems user patterns and their influence on systems performance are well understood. Evaluation of new concepts and products can concentrate on the use of short-term, in-depth system testing in the laboratory combined with analysis by simulation.

3.2.3 Performance Improvements

The main improvement in active solar performance over the last six years has been in achieving the outputs that were originally anticipated through simulation. For reasons like poor selective surfaces, undersized heat exchangers, and excessive piping losses, early performance results were erratic. Thorough monitoring has been instrumental in clearly quantifying the performance penalties of some options and in triggering efforts to find the solutions.

National Research Council monitoring studies have shown that the variety of configurations for DHW systems can give similar performance if some attention is paid to design. However, the specific design is important. Figure 4 shows how two system configurations with identical collectors, surface areas, and storage volumes can differ in performance. The best performing is a thermosyphon while the other is a forced circulation system with an undersized load-side heat exchanger.

Figure 4 also shows how important it is to properly size the DHW unit. Systems with annual solar fractions of 0.55 to 0.60 already provide 100% of heating needs in the peak summer months. To obtain a higher solar fraction the collector area must be sized such that some of the heat is rejected during the summer. This type of problem surfaced in some Maritime field trials when a few systems were oversized because the consumption of hot water by the families using the systems had been overestimated.

The importance of choosing appropriate applications also became clear through the Commercial Industrial Process Heating system trials of NRC. In these trials many of the systems were delivering only 1 GJ/(m^2•a) when design predictions called for 2 GJ/(m^2•a) or better. In some of these cases the energy studies induced by the solar project showed that a variety of heat recuperation schemes were economically attractive. With heat recovery the temperature regime of the solar system was pushed significantly higher and energy output dropped in consequence. Manufacturers and installers began looking for market niches in CIPH where there was a large low temperature demand that could not be easily met by heat recovery. Under these conditions experimental results at NRC showed that more than 3 GJ/(m^2•a) can be delivered.

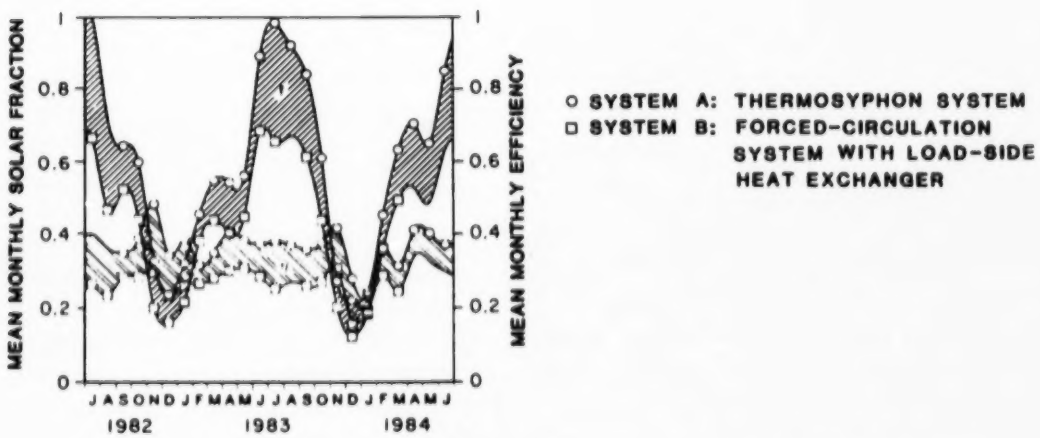


Figure 4. Monthly performance of two solar DHW systems (after Fig. 6, S.B. Beale and B.E. Sibbett, "Monitoring of Solar Domestic Hot Water Systems at the National Research Council of Canada," Proceedings of Intersol '85, June 1985).

3.2.4 Progress in Reliability and Standards

The reliability of active solar systems has improved considerably over the last seven years. In a 1979 evaluation study of the solar DHW technology available in Canada only one supplier was found able to install a reasonably operational system. Other units broke down with a combination of faulty controls, leaking or frozen pipes, pump failures, etc. The conclusion of the evaluation study was that considerable development of the technology was needed. Essentially the same conclusion could have been reached in 1979-1982 experience with commercial and industrial process heating (CIPH) applications of solar.

The R&D and field experience from 1979 on gradually enabled the industry to identify the faulty components. New systems were designed to avoid their use (e.g., air vents), use more appropriate products (e.g., pumps), or develop new products (e.g., controllers, collectors). The techniques for installation became more refined. Courses sponsored by the Canadian Solar Industries Association were held across Canada and good texts were prepared in collaboration with NRC.

The relative advantages and disadvantages of different design options became better understood. The closed-loop, glycol DHW system dropped in popularity as maintenance appeared too sophisticated for the average homeowner.

Work on standards in Canada has been done in collaboration with other international groups. Present tests for durability and for performance are similar to those used in the United States. However, research done at the Solar Calorimetry Laboratory of NRC and at the National Solar Test Facility (NSTF) has led to proposals for important modifications to the performance tests.

Special efforts were made in this field because tests had shown that the evacuated tube and the boiling/condensing collector designs were not well characterized by the methods adopted to fit the collectors' efficiency curve to the Hottel-Whillier-Bliss (H-W-B) representation. Figures 5 and 6 show the effects on performance of different irradiance levels. With ASHRAE 93-77, test irradiance levels are typically of the order of 900 W/m^2. The method thus does not capture essential information at other irradiance levels. Moreover, it appears difficult to determine the appropriate characterization from the H-W-B representation with a small number of measurements.

Figure 7 is the alternative representation recently proposed for Canada's solar collector standard, CSA F378-M1982. The output is seen to be a linear function of irradiance for a given temperature difference between

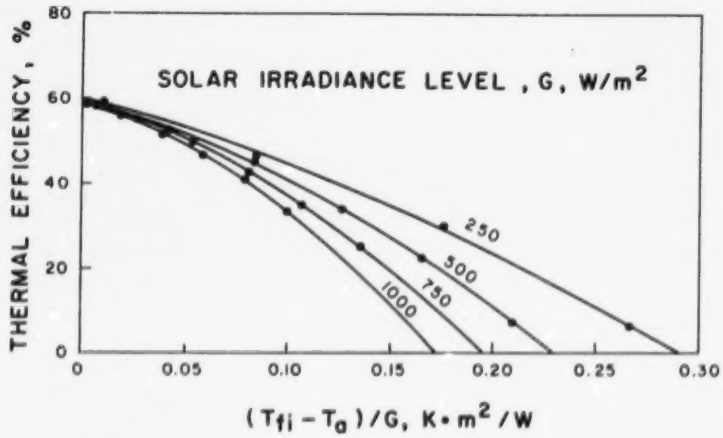


Figure 5. The thermal efficiency of a vacuum tube type collector as measured for different test irradiance levels (after a figure in S.J. Harrison, "The Effects of Irradiance Level on Thermal Performance Tests of Solar Collectors," Proceedings of Intersol 85, June 1985).

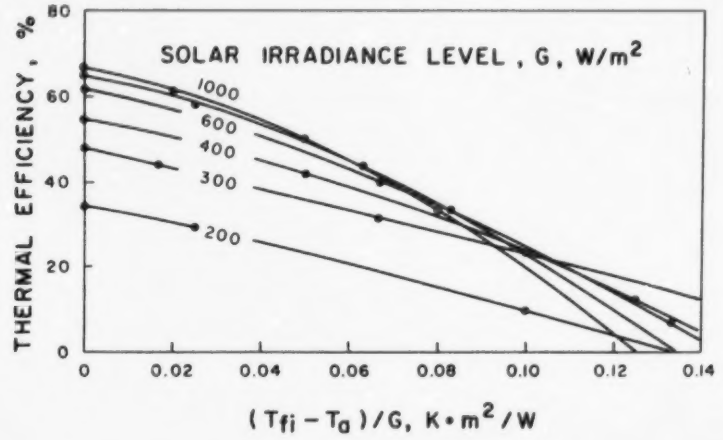


Figure 6. The thermal efficiency of a flat plate solar collector incorporating a boiling/condensing heat transfer fluid and integral condenser (after a figure in S.J. Harrison, "The Effects of Irradiance Level of Thermal Performance Tests of Solar Collectors," Proceedings of Intersol '85, June 1985).

fluid inlet and ambient. This allows a few measurements at two irradiance levels and a series of ΔT's to determine a collector's performance. The general equation that has been found to fit all cases is of the form

$$N = (a + b\Delta T)(G - G_T)/G - c\Delta T/G - d(\Delta T)^2/G$$

where a, b, c, d and G_T (the threshold irradiance) are constants for a specific collector

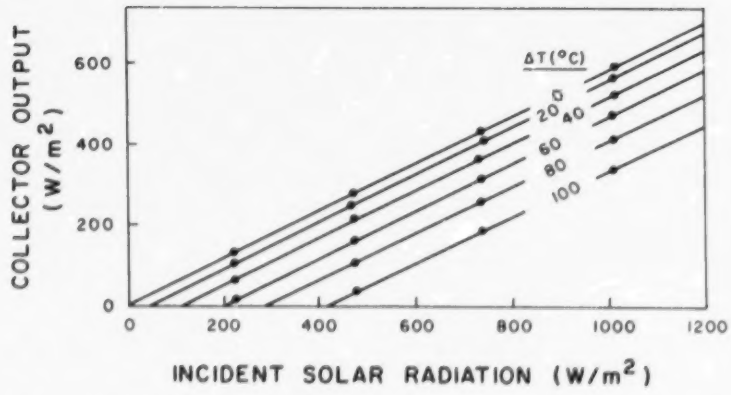


Figure 7. Collector input-output curves for conventional evacuated tube collector (after a figure in S.J. Harrison, "The Effects of Irradiance Level on Thermal Performance Tests of Solar Collectors," Proceedings of Intersol '85, June 1985).

G = irradiance

ΔT = difference between collector fluid temperature T_{fi} and the ambient air temperature T_a

The new approach to testing is important to evacuated-tube technology because higher and more accurate estimations of performance under typical conditions can be made. For the boiling/condensing collector it is important for another reason. $F_R\tau\alpha$ and F_RU_L values (the y-axis intercept and the slope of the thermal efficiency curves) obtained from ASHRAE 93-77 lead to overestimates of actual performance. Because the lower real performance has been noted, it often has been assumed that there was something wrong with the collector. The realistic characterization explains the differences between earlier estimates and actual results.

The work on the solar DHW system's performance test based on ASHRAE 95-1981 and on CSA F379.1 was mentioned briefly in the monitoring section. More research is needed to clarify some of the most recent results, but it appears that the test can be very useful. The poorest performance estimation was 10% in error and this was for a system that had very particular characteristics (severe cycling on and off) in actual operation.

The creation of the National Solar Test Facility constitutes in itself an accomplishment of the Canadian solar program. Tests with its indoor solar simulator have been shown to be in excellent agreement with outdoor results. The indoor facility allows much quicker testing of equipment and the irradiance-adjustable simulator lamp gives new scope to testing. In particular, it greatly facilitates measurements for the new input-output presentation. One important benefit of the testing program of the NSTF is the added credibility to Canadian products.

3.2.5 Innovative Technology Development in Canada

Many innovative concepts were examined to improve the competitiveness of solar energy and a few of these have emerged as worthy of continued research and/or of commercial development.

One concept that has survived from the very beginning of the accelerated solar development program is the boiling/condensing collector with integral condenser. It is a unique collector using a heat transfer process of which little was known prior to the solar research. Figure 8 illustrates the principles involved. The solar-heated absorber fins transfer the heat to the riser tubes within which there is a water - propylene glycol solution under its own vapour pressure. The heat causes a boiling of the liquid, the rising bubbles coating the entire riser tube with a thin film thus enhancing the overall boiling action and heat transfer. The mixture of gas and liquid spews from the top of the riser tubes and is directed onto an inner header pipe where a combined phase change, sensitive heat transfer takes place. The condensed liquid returns to the bottom of the collector through a pipe connected to the outer header.

A number of serious problems had to be resolved to convert this concept into the practical one it is today. In the early versions superheating of the liquid was occurring prior to boiling. This decreased the effective

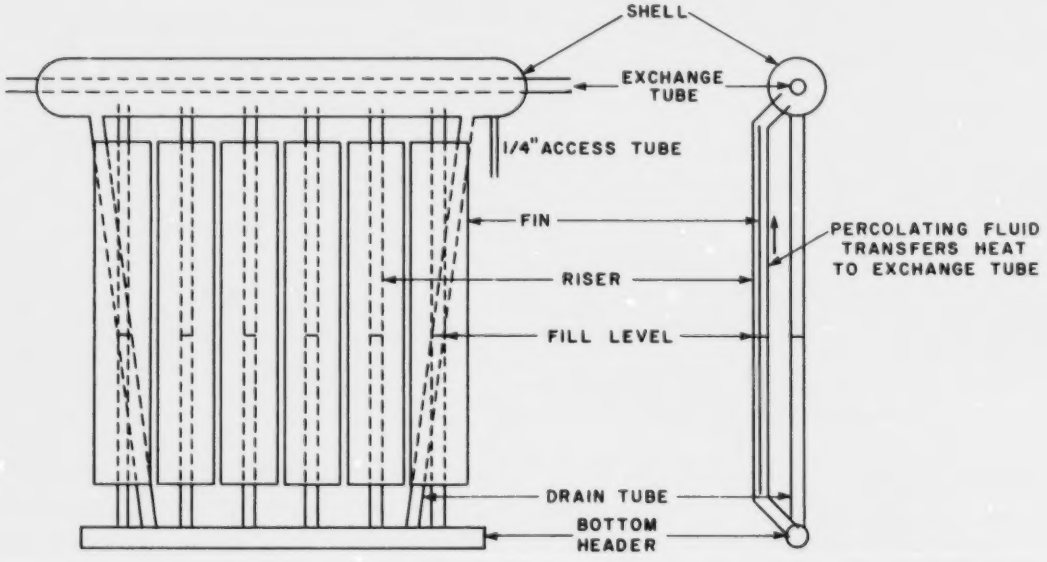


Figure 8. A boiling/condensing collector with integral condenser (derived from the Norsun collector model).

heat transfer so that a nucleating site was added to initiate boiling as soon as possible. Contaminents in the form of non-condensible gases were found to be very detrimental to performance and it was concluded that special care was needed in the manufacturing process to avoid this contamination. Optimization studies have determined the proper fluid solution, pressures, riser tube diameter, and geometric configuration of the header.

All of this has been done to exploit two major advantages of the collector design. One is its characteristic of being a thermal diode. It is efficient in transferring heat from the sun-warmed absorber to the distribution system. However, a cold absorber is isolated from the distribution system as the inner tube of the header is in this case surrounded by a partial vacuum. This allows important simplifications to be made in the means of providing freeze protection.

Another advantage of the design is the simplified distribution system. The collector inlet fluid flows only through the inner tube in the header and not through the collector absorber plate. Pressure losses are reduced and reverse-return piping for arrays is no longer necessary. The advantages of the thermal diode collector are shared by the heat pipe concept (as is used in one of the evacuated tube collectors). Which of these two related heat-transfer concepts will eventually prove more cost effective will depend on the result of further design refinements. Below are given a few more examples of Canadian innovation in active solar technology.

- Connectors between collectors in arrays have, until recently, been relatively cheap but leak-prone, or effective but expensive. In the former category are hose connectors with clamps; in the latter category are metal bellows connectors. A long search for a cheap and effective solution has led to the development of a short brass tube with one large central O-ring and additional O-rings at each end. It is a new and unknown Canadian product now but soon it should be extensively used because of its obvious advantages.

- A selective surface that absorbs well the solar radiation but re-emits very poorly in the infrared has been shown to be one of the most effective measures to use in improving the performance of solar collectors. Production techniques for the deposition of these surfaces on both copper and aluminum substrates are among the most advanced in Canada. Canadian companies are major suppliers of selective-surface absorber plate to collector manufacturers in the United States.

- To use solar energy for illumination is hardly a new idea but to do so well within the interior of a building required the invention of the light pipe. It relies on total internal reflection at high incidence angles to provide low-loss light transmission through it. The key

technical feature is a very fine prismatic corrugation on the the outer edge of the plastic pipe surface. The applications now tend to be specialized, such as providing lighting for dangerous areas where the light source should be external to the working area. Wider use will come, especially in areas with substantial cooling loads where it is preferable to have the light source (also producing considerable heat) external to the air-conditioned area.

3.3 The Economics of Active Solar in Canada

Canada is endowed with a variety of energy resources available at prices among the lowest in the world. It is useful to convert these energy prices into cost performance figures that would lead to certain levels of market penetration for alternative sources. The threshold values of Table 1 are given in initial cost per unit annual energy savings and are as broadly representative as possible. Certain energy prices such as electricity in the Maritimes are higher, and others lower, especially for natural gas, but these thresholds still reflect reasonable goals if wide-scale market penetration is sought.

Arguments have been proposed that active solar costs should be judged against certain social opportunity costs. Environmental costs of using fossil fuels are hard to quantify, so the government has based this opportunity cost in the case of oil and natural gas on the profits foregone by exporting the energy. But domestic oil prices are now above world oil prices, e.g., 0.31 \$/L = 35 \$U.S./barrel. So, for these two fuels, solar

Table 1. Threshold cost performance values for Canadian market penetration[1]

Market type	Economic criteria	Threshold \$/(GJ·a^{-1})
Residential and commercial new building market plus innovators in residential	Energy savings just compensate for additional mortgage payments to cover investment in solar system	90-120
Residential and commercial general market	5-year payback for residential sector 3-year payback for commercial sector	50-55
Industrial energy supply	3-year payback	30

[1]The specific calculations are based on a price of electricity of 0.045 \$/kWh for the residential sector, 0.051 \$/kWh for the commercial sector and 0.0275 \$/kWh for the industrial sector. The equivalent price for oil at 65% heat conversion efficiency is 0.31 \$/L (this is lower than most Canadian market prices) and 0.31 \$/m^3 for natural gas (higher than present market prices). The mortgage is based on a 6% real rate of return with 10-15 years for repayment. For the payback periods of CIPH applications account had been taken of class 34 of the income tax regulations that allows for a rapid 3-year depreciation of certain investments in renewable energy and conservation projects. The thresholds in the commercial and industrial sectors can about double if third-party financing is introduced when very high confidence is established in the reliability and durability of the products.

systems should aim to compete openly on the Canadian market. In the case of electricity, it is argued that solar should compete with the marginal cost of introducing new electricity. However, with active solar in its present form, it has little or no capacity credit. In studies by Ontario Hydro it was found that a good market penetration by solar DHW systems would actually exacerbate the utility's load peaking problems. Only when economical seasonal storage is found will active solar be able to claim to displace marginal electrical costs in Canada.

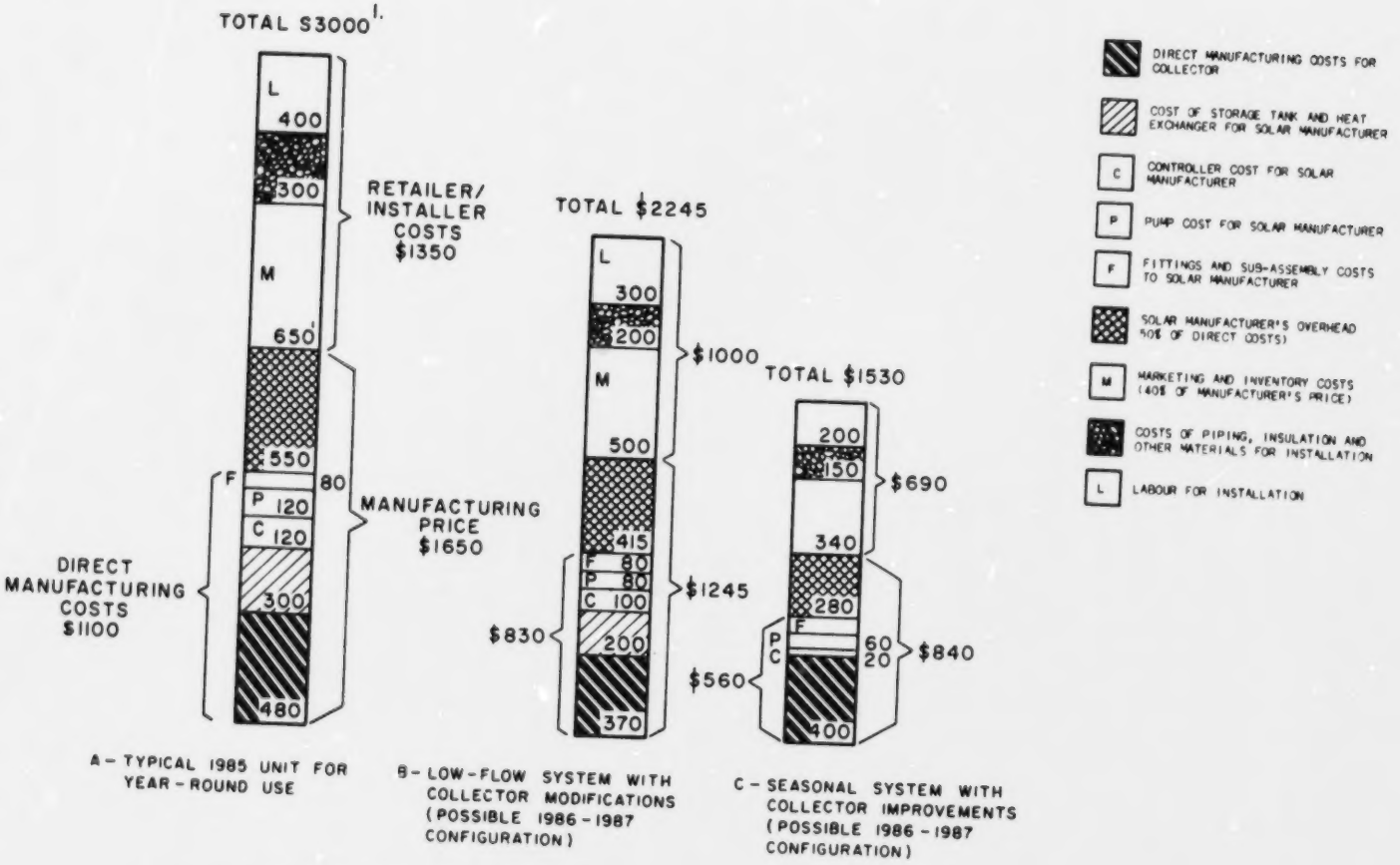
The preceding brief discussion of the economics of active solar has not touched on issues such as resiliency. It may be socially wise to support a certain level of solar market activity that encourages industrial development. Then in the event of an unexpected disruption in the availability of conventional fuels, solar would be among the alternatives that could be exploited within a reasonable time. A debate on the value of active solar in this context is beyond the scope of this paper. Nevertheless, it can be stated that recent progress in the technology makes limited market support much more practical given the decreased incentive needed to make solar attractive to the public. Furthermore, experience gained through the whole energy R&D program shows why the development of alternative supplies should be planned well ahead. Earlier optimistic predictions that new sources could rapidly be brought on-line proved unrealistic.

3.3.1 The Economic Analysis of State-of-Art Active Solar

The first part of Figure 9 gives the breakdown of costs associated with the installation of a state-of-art solar DHW system. Figure 10 gives the breakdown for the manufacture of the collectors alone. The system is a drain-back that should produce 10 GJ/a with an average family load of 225 L/d of hot water. The overall retail cost of $3000 combined with its output give a cost performance figure of 300 $/(GJ•a^{-1}). Without subsidies or tax credits of some form this figure is far too high to give any significant market penetration in Canada or elsewhere.

The best cost performance attainable for active solar applied to CIPH applications is in very low temperature applications with small collector areas (50-100 m^2) of the type used for heating swimming pools. For example, a good application of this nature would be for heating water in fish farms. Unfortunately the number of these applications appears very limited.

With larger loads and collector areas the polymer collector loses its advantage over the single-glazed metal collector as the flow rates needed for the polymer collector occasion important piping costs. The cost breakdown for a system with a large array of single-glazed metal collectors is presented in Figure 11. With a system output of 2-3 GJ/(m^2•a) giving an



1. SYSTEMS CAN AND HAVE SOLD FOR $2600 WITH MANUFACTURERS BEARING PORTION OF DIRECT MARKETING COSTS

Figure 9. Cost breakdowns of solar domestic hot water systems. (The cost figures are derived from a number of NRC contract reports. One with an overview is "Upgrading of Solar Domestic Hot Water Packages" by E.W. Hoffman, July 1985.)

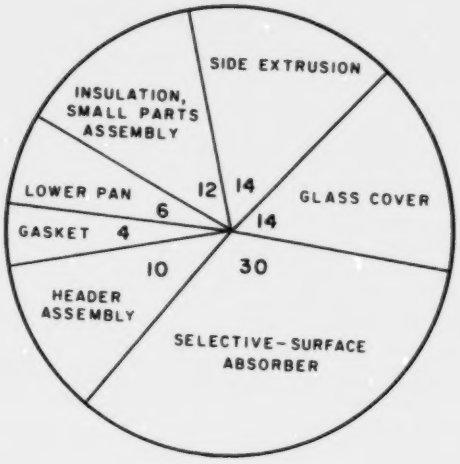


Figure 10. Cost breakdown of a state-of-art solar flat-plate collector. (These cost figures are derived from a number of manufacturers' reports submitted to NRC.)

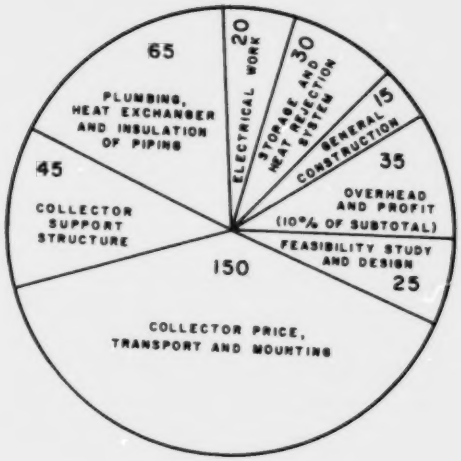


Figure 11. Cost breakdown of a state-of-art solar system for an industrial application. (The costs are based on a number of contract reports submitted to NRC.)

overall cost performance figure of 130-195 $/(GJ·a^{-1}), this solar CIPH option is now far from being economically attractive.

3.3.2 The Economics of Potential Developments in Active Solar

Some straight-forward simplifications in collector design for DHW systems still can be made. The box assembly is now too expensive for what it does, protect the absorber and hold the cover plate. Brake-formed metal rather than extruded aluminum is already used in some foreign products. Reductions are taking place also in the absorber plate technology. Selective surfaces on copper at 10 $/m^2 are being challenged by lower-cost selective surfaces at 2-3 $/m^2 on aluminum. With the low-flow design the header can be eliminated and the riser-tube diameter reduced in a serpentine flow pattern. A direct cost of 60-70 $/m^2 as opposed to the present 90-100 $/m^2 can be envisaged by adopting these measures.

The progress in the development of durable, resistant polymer film glazings promises to allow much lighter collectors that will reduce not only material costs, but facilitate greatly the installation. New tensioned structures are being developed to exploit fully these developments. Research is also being pursued in the United States to use very light laminated absorbers. However, a move in this direction necessitates the use of a low-pressure, indirect flow regime (the collector circuit is isolated by a

heat exchanger from the potable water supply and the mains pressure) that limits the potential for cost reductions in the rest of the system.

The low-flow concept was first touted for its potential to improve the efficiency of solar DHW systems. Rather than circulating fluid through the collector to yield a temperature rise of a few degrees Celsius the flow is reduced to the point that one pass in the collector loop brings the fluid up to the desired temperature of 55°C under sunny conditions. The high temperature and low flow make stratification possible in the storage tank and this increases the efficiency of the system.

The low-flow system reduces costs of solar DHW systems by allowing the use of small diameter tubing to join the collectors to storage. As the heat loss is inversely proportional to the ratio of outer to inner diameter of the insulation surrounding the pipes, the small tubing allows smaller quantities of insulation to be very effective in keeping heat loss to a minimum. The combination of all these factors should soon bring down costs for solar DHW systems to below $2300 (i.e., a 20% reduction).

The low-flow concept has already been successfully integrated into a seasonal solar DHW system offered in Canada which synergistically combines this concept with that of the thermal diode collector (a heat pipe technology would also work well). Major cost reductions are achieved through the elimination of the heat exchanger and the secondary storage tank, through a much simpler controller, a smaller circulating pump, and simple installation of flexible tubing. Installed costs about $1500 are possible with this approach. Tests at NRC with a similar system indicate that only 15% of the annual output is lost by not operating this solar DHW unit during the four coldest months.

How the two concepts work so well together is worthwhile describing in more detail. Because heat losses from the collector header are so small, direct flow with potable water and a simple control strategy can be employed. A timer turns on the small pump during the principal daylight hours. With good sunny conditions the storage tank simply fills up with hot water. On a cloudy day the water from the collectors enters the top of the tank and turns on the thermostat controlling the upper heating element. The storage tank gradually fills with hot water because the water is slowly being circulated past the upper element.

This seasonal solar DHW system represents one of the best now available in terms of straight cost performance. Its marketability could be increased by further measures to eliminate any possibility of catastrophic failure due to inadvertent operation in very cold weather (freeze protection is now provided by a drip valve which is effective to well below 0°C).

Refrigerant-charged systems as an alternate freeze-protection method have been well studied in Canada. Research is still ongoing to realize a number of potential cost reductions in this field. The materials costs are reduced through the wider use of aluminum that does not corrode in contact with the refrigerant. The phase change of the refrigerant can be used to activate an automatic pump that eliminates the need for a controller and lessens the cost of the pump itself. The piping to and from the collectors can be flexible and small in diameter. The combination of these measures should give a very reliable system below $2400 in price.

The main direction taken in trying to reduce costs of large CIPH solar systems has been in working to achieve economies of scale through the site assembly of modular collector units. While total costs from special demonstration projects of this concept are in line with costs from discrete collector arrays, it still appears possible with experience to make significant cost reductions in this field. Figure 12 shows the essential features of a large site-assembled collector. Its advantages are as follows:

1. The efficiency of the collector is improved by about 3-5% because the ratio of net to gross aperture area is increased and side losses have been decreased.
2. Upper and lower collector headers and interconnections have been replaced by headers only at the end of the collectors. The net cost saving is of the order of 30 $\$/m^2$.
3. The support structure and the collector box are integrated and made from the same inexpensive corrugated metal. Net cost savings are about 50 $\$/m^2$.

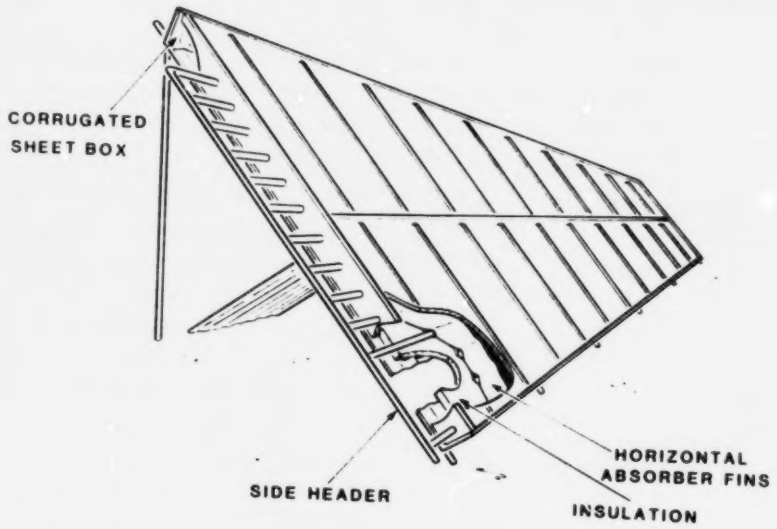


Figure 12. A large site-assembled collector for industrial applications (derived from information provided by PetroSun Inc.)

4. Piping is greatly simplified with one central axis for the main inlet and return lines. There are no pipe returns from the opposite ends of the array. Cost saving is of the order of 10 $\$/m^2$.
5. Installation costs will be increased because of the need for an experienced crew to handle the new assembly details. This should add some 15 $\$/m^2$ to costs.

In summary, cost reductions of about 25-30% appear possible for large solar industrial systems using the site-assembly techniques. However, this will require a market development that is difficult to envisage at the moment. The development of durable polymer film glazings could produce further significant cost reductions with this approach.

4. PASSIVE SOLAR

4.1 International Perspective of Passive Solar

Passive solar technology integrates the collection, distribution, and storage of energy into the design of a building itself. As building techniques vary widely from country to country and as the relative needs of heating, cooling, and daylighting are strongly affected by climate, appropriate passive design tends to be specific to a given area.

The principal advantage of a passive system is that most components serve a dual purpose, e.g., the windows are both collectors and part of the building envelope, so the costs attributable to solar use can be small. For a new wood-frame house there are no direct incremental costs in construction to attain a solar contribution of about 20-25% to the space heating needs. The barrier to wider use of a simple passive direct gain concept is the lack of off-the-shelf designs and lack of an informed construction industry and public. Basically this type of house is designed to use the sun's energy profitably at the same time it is available. However, as higher solar fractions are sought, more and more emphasis must be given to storing the energy from the day for night-time use. Otherwise, uncomfortable overheating of the house occurs.

In the South West of the United States or in countries like Greece it appears practical to use the "mass and glass" approach to attain high solar fractions. Similar to the adobe dwellings of much earlier times the strong temperature variations from day to night in the dry climate are smoothed out by significant thermal mass (a great deal of stonework and masonry) within the building. This approach has become popular as much from the perceived agreeable lifestyle of open light spaces and plants as from the energy savings potential.

With the present technology it appears most practical for northern climates like Canada's to design a new house in order to take the readily available 20% solar contribution and put any additional resources into improved conservation. One designs for that solar fraction not by adding window area but simply by emphasizing south-facing windows and by having the larger rooms directly behind these windows.

Besides the above-mentioned direct gain system, other passive possibilities are indirect gain systems like the Trombe wall or isolated gain systems like a solarium. These strategies are attempts to better control the temperature of the central living zone. The Trombe wall has very limited usefulness in a colder climate because the thermal storage is just beside the window, the part of the building envelope with highest thermal losses. In the isolated gain system one has simply displaced the over-heating

problem. To make the solarium livable one has to work seriously at controlling the temperature. A solarium perceived only as a source of heat becomes a very expensive collector.

The keys to enhanced direct gain systems in northern climates are windows that provide better thermal resistance, and effective storage systems for the surplus daytime heat. Suppliers are starting to offer the better products that typically provide the equivalent resistance of a triple-glazed window or slightly better. Research in Canada is at the forefront of efforts to provide even higher thermal resistance for the next generation of "super" windows. The search for cost- effective storage systems has found no clear winners yet but modest progress has been made in the use of phase change materials.

Passive solar tends to almost exclusively be identified with the residential sector. However, reductions in conventional energy use can be realized in commercial buildings with proper energy management and some passive hybrid features. (Passive hybrid refers to integrated systems involving some auxiliary energy use typically for better distribution of heating or cooling.) For high-rise office buildings in warmer climates the lighting and air conditioning loads dominate and emphasis is on reducing these loads through fenestration design. Products such as light pipes have an interesting potential for these applications. In colder climates heating becomes more important, especially for glazed curtain-wall buildings. The emphasis is on transferring the gains from the south to the north zones with sophisticated energy management control system.

4.2 Canadian Accomplishments in Passive Solar

The ultimate aim of passive solar and conservation programs is the same: to reduce energy consumption in buildings in an economic manner. Both programs seek to achieve this by integrating features into the building construction itself. Each program must constantly evaluate the progress made in the other to assess the impact on priorities for research and for choosing the most cost-effective options.

Yet, with all these similarities, the Canadian passive solar and conservation programs have been distinct and healthily competitive. Conservation has focussed on simple building trade practices, increased insulation levels, continuous vapour barriers, etc., to produce savings. The passive solar program has quantified possible solar contributions, researched technological solutions to improve window performance, and worked on total energy management within the building. Thus, passive solar in Canada should be viewed in a very broad sense.

4.2.1 Energy Performance and Design Guidelines

Although simple in design, passive solar systems are complicated to analyze and detailed data from high-level monitoring are necessary to verify the basic algorithms proposed to predict energy performance. Data have been obtained on the NRC campus with high-level monitoring of a series of unoccupied huts having different passive solar options. The quality of the data is such that it has been widely used through the International Energy Agency to verify the performance predictions of a number of simulation models. Some of the data are still being analyzed to develop algorithms that will predict overheating time for direct systems and the energy performance of isolated-gain (solarium) systems.

The analysis of direct-gain systems has led to the development of simple methods for the prediction of energy performance. Solar radiation data and transmission figures for the glazings give the solar gains over the heating season. The fraction of this gain that is useful (the solar utilization factor in Figure 13) is determined as a function of the mass to solar gain ratio, the solar-gain-to-total-load ratio, and the temperature swing the homeowner is willing to accept (0, 2.75, or 5.5°C). The load minus the product of the solar gain and the utilization factor then gives the purchased heating fraction (Figure 14).

The utilization factor curves prove to be widely applicable across Canada. In Figure 13 slight discrepancies are seen for Vancouver where the universal curves overestimate the real utilization factor (even here this typically leads to errors in purchased heating fraction of only 6%). This results from the mass-to-gain ratio being defined from the average solar gain per day. The maritime winter climate of Vancouver has a distribution of a very few sunny days with many cloudy days so that the relation between a sunny-day gain and the average-day gain is different from most other Canadian cities.

The implications of this research on present passive solar design is the understanding that for wood-frame construction in Canada the optimum south-facing window area for lowest energy use is modest. The simple passive design in Canada does not have more window area than a normal house. The only difference is that due account is taken of window orientation, with south-facing windows taking preference over west and north windows.

The analysis of some of the results of monitoring an attached sunspace and of the heat transfer from it to the parent building is underway in the Institute for Research in Construction (formerly the Division of Building Research) at NRC. The information already available, however, is sufficiently compelling for designers to reconsider this approach, at least as a prime means of collecting and using solar energy. Most people acquiring a

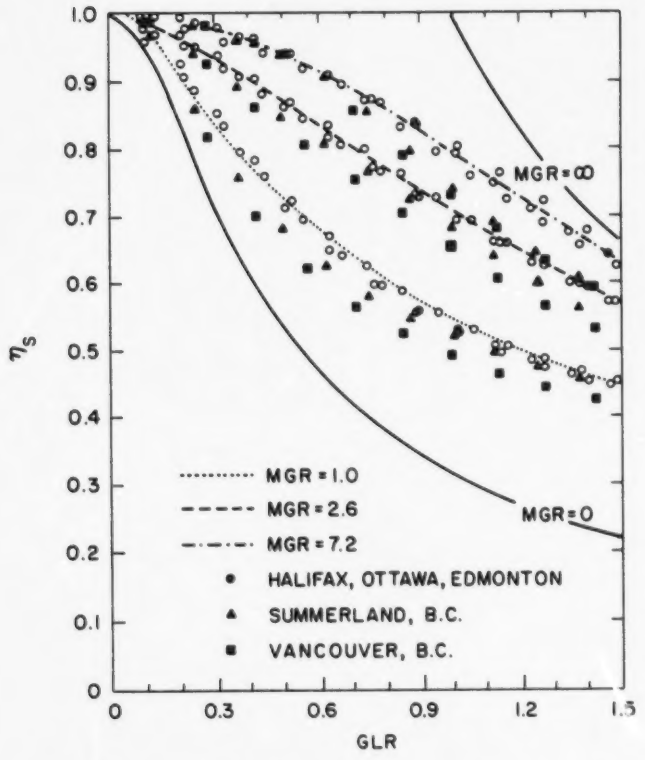
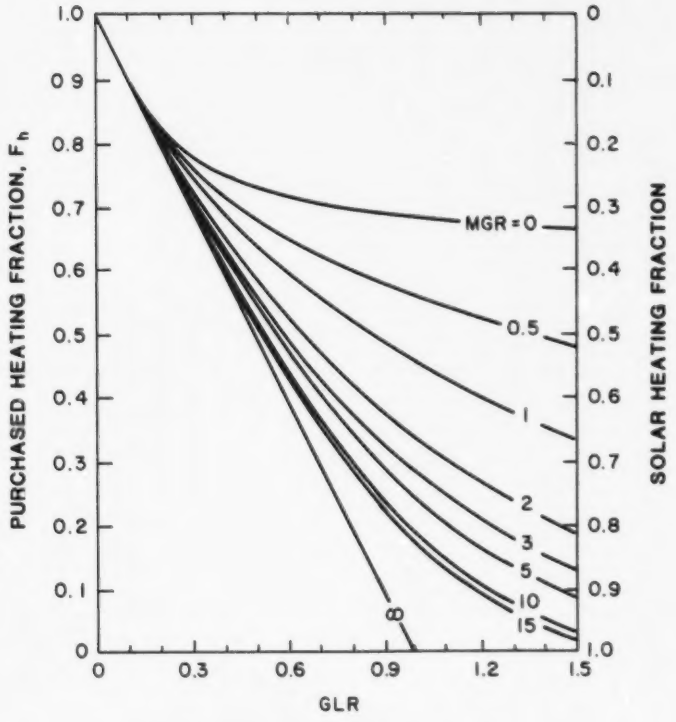


Figure 13. Seasonal solar utilization curves and actual data points for five locations (after a figure in S.A. Barakat and D.M. Sander, "Utilization of Solar Gain Through Windows for Heating Houses, Building Research Note No. 184, National Research Council, Ottawa, Ont., March 1982).



n_s = SOLAR UTILIZATION FACTOR
MGR = MASS-TO-GAIN RATIO (h/°C)
GLR = SOLAR GAIN-TO-LOAD RATIO

Figure 14. Seasonal purchased heating fraction (after a figure in S.A. Barakat and D.M. Sander, "A Simple Method for Determining the Heating Requirements of Direct-Gain Passive Solar Houses," Building Research Note No. 195, National Research Council, Ottawa, Ont., September 1982).

solarium are looking first of all for a certain aesthetic improvement in quality of living through an open, light sunspace. Secondly they are looking for an energy-efficient design. To respond to the first goal the solarium must have a tempered climate suitable for occupancy over a large part of the year. But the vast window areas associated with sunspaces typically have a very high net energy gain during the day and a high net energy loss in the night that make it very difficult to realize either the tempered climate or the energy efficiency. The goals may be achieved but only with great care taken in the design stage.

Figure 15 shows the temperature variations in the low-mass sunspace on the NRC campus with 16.3 m^2 net floor area and 9.9 m^2 glazing area. Obviously very little use of the sunspace could be made under these severe climatic conditions. An important quantity of thermal mass within the sunspace has helped to improve somewhat the livability of this area in later experiments, but it is far from a sufficient solution. Good ventilation is also a prerequisite.

The experiment relied on forced convection by fans to transfer heat from the sunspace to the parent building. This did not appear to be very efficient. With 38% greater solar gain to the sunspace as compared to the reference direct-gain system, the utilized solar gain by the parent building was only 50% of that of the direct-gain system. However, the sunspace reduced by 40% the heat loss from the building so that auxiliary heating of the parent building with sunspace was 75% of that required by the direct-gain unit. In this case the heat loss reduction was more important than the solar gain. If the sunspace were maintained above a minimum temperature at night the heating requirements would far outweigh these heat loss reductions.

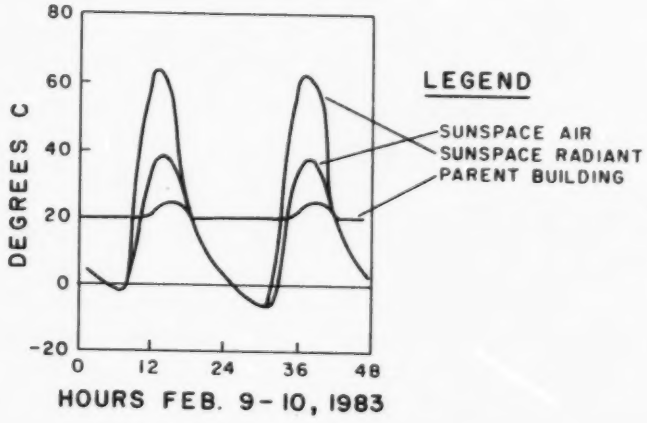


Figure 15. Temperature variations in the sunspace at NRC (after a figure in K. Ruberg, "NRCC's Sunspace and Direct Gain Test Facility: Thermal Performance During 1982-83 Heating Season," Division of Building Research, National Research Council, Ottawa, Ont., #1320, August 1984, NRCC No. 24950).

Level-B monitoring has been carried out on a number of passive solar options that typically seek to augment the passive solar fractional contribution by transferring the day-time solar gains to some thermal mass for night-time use. Some have used rock beds. The technical capacity for making efficient rock bed storage beds does exist because of some detailed studies carried out in this field. The practical use of this method and others has succeeded in moderating temperature swings but has not been economic when comparing the energy saved to the additional costs for the energy storage.

Again the overall conclusion in residential construction is that with present technology only modest passive solar contributions should be sought when economic energy efficiency is sought. For the sunspace this means that only the window area necessary to produce the desired lighting levels should be used. To avoid overheating in summer and reduce costs, the windows are best left vertical and oriented to the south. A retrofit of a sunspace on to a patio door may make good sense as this will limit the heat loss from the door. In the same line of thinking, glazing between the solarium and the main home gives clarity and solar energy to the main residence area with lesser losses than with the glazing directly exposed to outside conditions. The construction itself of a sunspace is not a trivial matter. Studies carried out on behalf of NRC in the field have led to a book about to appear on good construction practice.

While the guidelines stated above apply well to the mainstream of housing construction it remains important to monitor new concepts and evaluate their potential for economic energy efficiency. The Solar Energy Program has had success in the use of a Level-B Monitoring Manual to evaluate some alternative approaches to passive solar design. The cost incurred per project ($25 000) and recent advances in data acquisition equipment suggest a modified approach for the future. The new equipment allows much faster analysis through ready link-up of the data to versatile programming systems. The new monitoring methodology would use this capability to define the principal characteristics of the building over a period of about 1 month and then rely on energy integrating meters and feedback from the occupants to verify the anticipated performance of the house.

A number of special studies have been carried out to assess the potential of passive options for different building types. The studies of non-residential construction show clearly how new energy efficient measures can significantly improve the performance in this field, even though passive solar contributions themselves remain very modest. From some of the documents now available architects can adopt practical designs for such popular features as atria and can learn new ways of using advanced tools like DOE2.1B in simulation studies.

With the private sector throughout North America responding to the need for simple computer programs for passive solar residential design the role of the Solar Energy Program became that of sponsoring their evaluation. The feedback to the organizations offering these programs has been appreciated and notice has been received already of many improvements to these programs, both in terms of accuracy and of user-friendliness.

One of the Canadian programs, ENERPASS, has been very successfully used in a design study of options for an energy efficient condominium apartment building. A whole series of cost effective options were identified and actually put into the building. Triple glazing was cost effective even before energy savings were considered directly because it eliminated the need for a baseboard heaters beneath the windows. A California heat pump system (Figure 16) allows heat to be transferred from heat surplus areas to heat deficit areas. Other features incorporated were domestic hot water preheating, pool heating with a heat pump, heat reclaim from exhaust air, two-speed ventilation, heat storage to use low-cost electricity at night, and an energy-conserving garage design. The end result is illustrated in Figure 17. Energy consumption per unit floor area is about one third that of a conventional condominium.

4.2.2 The Super Window Program

One of the major challenges to better energy efficient housing is in the improvement of the thermal performance of windows. Current double-pane windows have a thermal resistance of about 0.35 $m^2 \cdot °C/W$ while walls about them are 6 to 15 times more effective in impeding heat loss. South-facing windows in small areas produce a net gain in heat but in larger areas they exacerbate passive solar design methods because of the special attention required to avoid large temperature swings from night to day. Current windows also make it necessary to have good heat distribution systems to compensate for their uncomfortable cooling effects. In new super-insulated houses window losses can account for 30% of total heat losses. The research into high-performance super windows has been one of the main focuses of the Canadian passive solar program.

One of the first concerns is identifying what factors can have an important effect on the performance of a window. A computer simulation program, VISION, has been developed that permits the assessment of almost any configuration of interest. It uses accurate equations to calculate the heat transfer and optical transmission for the glazing area. Figure 18 shows the effect of different pane spacing for multiple-glazing windows with one low emissivity coating to reduce infrared transmission. For very small spacings the heat transfer is dominated by conduction through the air. However, near 10 mm convection begins to be effective in heat transfer so that little further gain in resistance is made beyond this point.

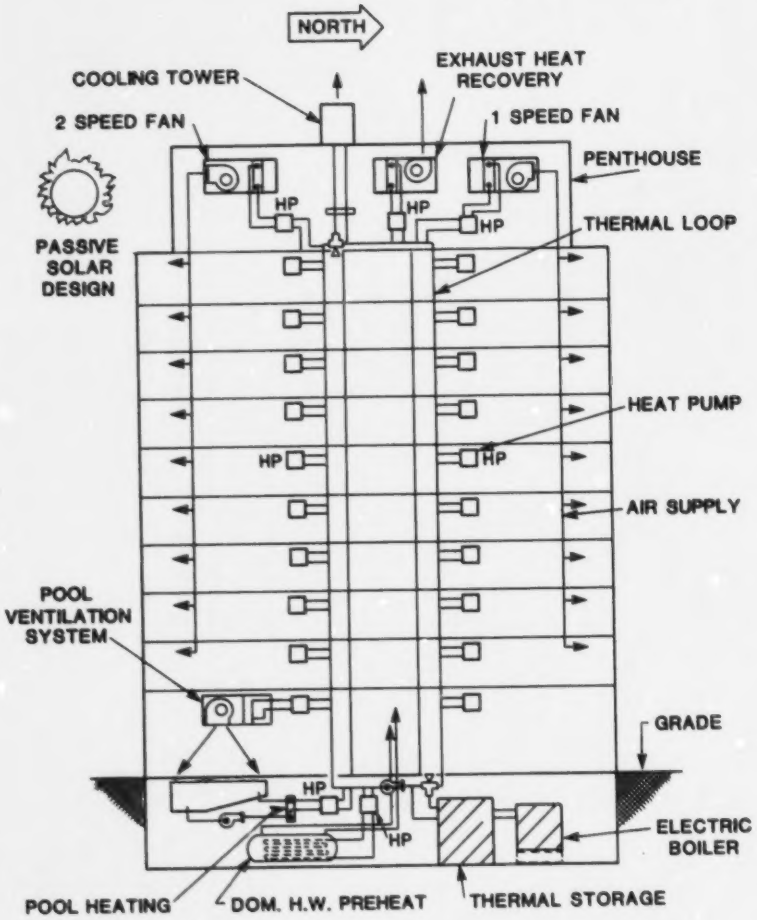


Figure 16. Schematic of a California heat pump system for a condominium (after a figure in "Passive Solar Hybrid Design for a Low Energy Apartment Building, Project Digest" by Engineering Interface Limited, April 1984).

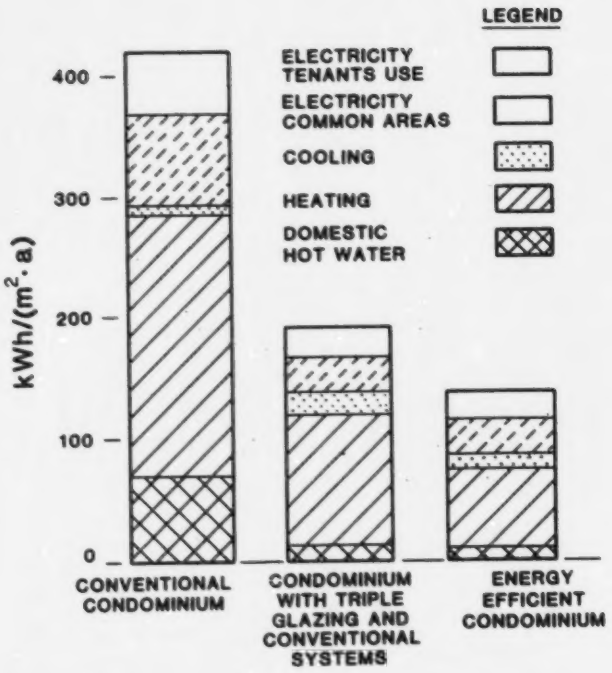


Figure 17. Energy performance of conventional and energy efficient condominiums (after a figure in "Passive Solar Hybrid Design for a Low Energy Apartment Building, Project Digest" by Engineering Interface Limited, April 1984).

Figure 19 shows the importance of that one low emissivity coating. Glass absorbs infrared radiation very well so at each glass interface the heat radiation is absorbed and reemitted. FEP film (known under the trademark of I.E. duPont de Nemour and Co. as Teflon) transmits well in the infrared so the film poses no barrier to thermal radiative transfer. The figure shows how unimportant this is when the low emissivity coating at one glazing suppresses the infrared radiation. It also indicates the promise for the design of combinations of outer glass glazings with interior thin-film polymers.

A number of projects have been undertaken to overcome the practical problems associated with super window design. Low emissivity coatings are available on the market but tend to be overly expensive and questions have been raised concerning their durability. One group has developed a very promising chemical vapour deposition (CVD) technique for low emissivity coating of glass. Other CVD techniques have not been successful because the uniformity of the thickness could not be maintained. An electrostatically charged spray solved this problem as charge repulsion keeps the spray droplets from coalescing.

Another approach for low emissivity coating, this time on thin-film polymers, has been demonstrated as promising for full scale-up to commercial

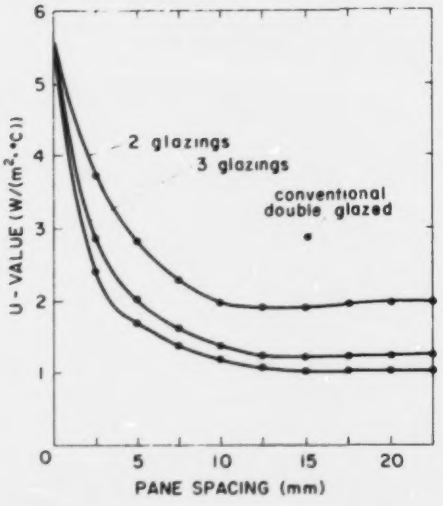


Figure 18. Heat transfer across multiple-glazing windows for different pane spacing (after Fig. 1, J.L. Wright, "The Computer Simulation of Super Window Glazing Systems which Incorporate Teflon (FEP) Inner Glazings," Proceedings of Intersol '85, June 1985).

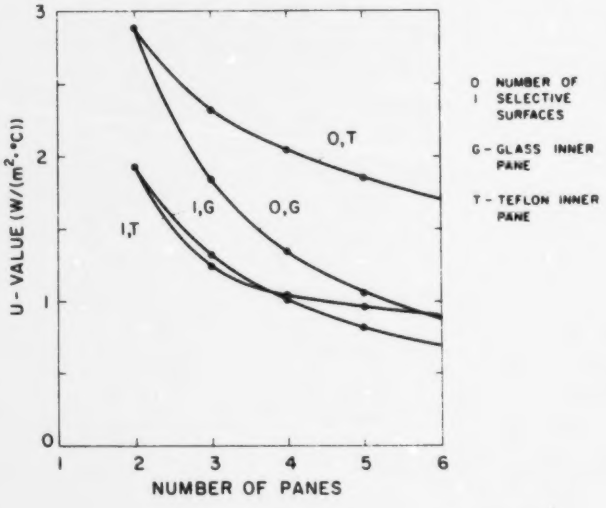


Figure 19. Heat transfer across multiple-glazing windows windows for different options (after Fig. 2, J.L. Wright, "The Computer Simulation of Super Window Glazing Systems which Incorporate Teflon (FEP) Inner Glazings," Proceedings of Intersol '85, June 1985).

production. The process involves an innovative biplanar magnetron sputtering unit and reactive deposition. A wide variety of coating materials can be used and many show excellent durability characteristics.

A number of studies have been conducted to devise practical thick window configurations. As the volume of gas contained between the glazings is increased so normally does the deflection of the glass needed to compensate for pressure variations due to heating and cooling. Only in recent years have triple-glazed units been available that offer high reliability and resist breakage over many years. The state of art is pushed to the limits with quadruple glazing units. No easy solutions to pressure compensation have been found in the Canadian passive program but attempts at solving the problem have been documented. A solid base of information exists for others to seek out the solutions.

The ultimate window unit would be a double-glazed unit with a very low emissivity coating to suppress infrared radiative transfer and a vacuum to eliminate heat conduction and convection. The crushing atmospheric pressure exerted on this glass unit poses a major obstacle to a realization of this concept. A Canadian project shows that it is at least technically feasible to produce such a window. It does not appear economically attractive now because of the need for 6-mm tempered glass in the construction. However, one feature of the design, a superior edge-seal, has attracted serious attention from industry. It consists of a flexible metallic band bonded directly to the edge of the glass.

In conjunction with the super window technology it is important to examine ways in which the advances can be fully exploited in buildings. Just as triple-glazed units made possible the simplification of the heat distribution system in the condominium of Figure 16, similar measures to reduce costs of heating can be envisaged for buildings with super windows.

4.3 Passive Solar Economics in Canada

4.3.1 The Economic Analysis of State-of-Art Passive Solar

It has been stated earlier that a state-of-the-art passive solar design with cost effectiveness in mind simply emphasizes south-facing windows without adding window area beyond that which is aesthetically desired. From an economic standpoint the first question to be answered is: Are the passive gains large enough to be worth considering at all? The energy gains vary across the country but Ottawa's figures being intermediate to the continental and maritime climates give a good indication of what can be obtained. The specific values given below are all based on Ottawa's climate.

For a net area of 1 m^2 of double-pane glazing there is a difference of 0.9 GJ/a of gain between a south- and north-facing window (Figure 20). At 0.045 \$/kWh or 12.5 \$/GJ this gives a saving of 11 $\$/m^2$. With 10-20 m^2 of glazing adaptable to a south location in a house the overall benefits are a non-negligible 110-220 \$/a. West and east windows perform intermediate to the two extremes of north and south over the heating season. However, during the summer the solar gains are maximum for the west and east windows and are less easy to control with overhang than south windows. For this reason east and especially west window areas are kept to a minimum.

Can adding window area to the south beyond that which is aesthetically desired be justified from the economic savings? Replacing a wall with an RSI of 3.5 $m^2 \cdot °C/W$ by a conventional double-glazed window would give a net gain of 0.4 $GJ/(m^2 \cdot a)$ in the Ottawa area if all the solar gains were utilizable. These values take into account thermal bridging effects of the sash of the window and frame, which are not negligible (Figure 21). With a threshold for cost effectiveness of 120 $\$/(GJ \cdot a^{-1})$ some 50 $\$/m^2$ could be justified in extra expenses for the window. However, as the windows cost about 180 $\$/m^2$ and as a wall of this type could be built for 70 $\$/m^2$, even under the best of circumstances it is hard to justify added window area.

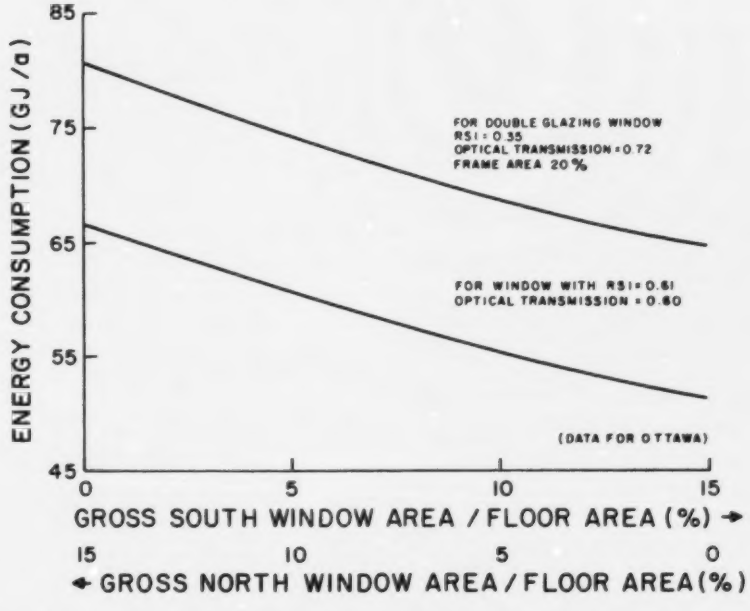


Figure 20. Variation of energy consumption of a house as a function of the orientation of the windows (from recent NRC contract work by S. Carpenter of Enermodal for NRC).

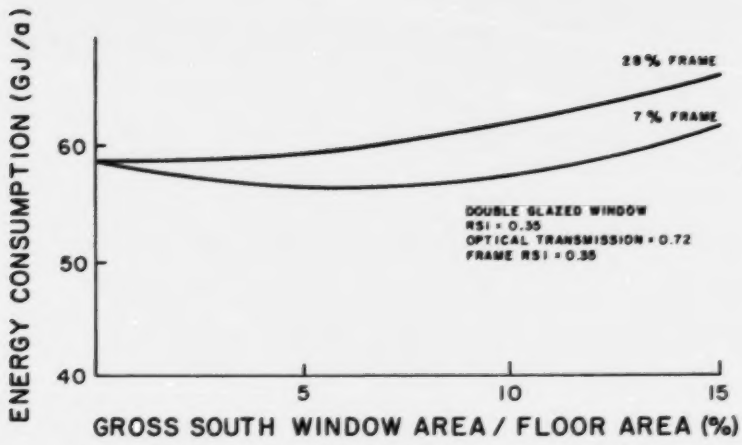


Figure 21. Energy consumption versus south window area with double glazing and two different ratios of glazing-to-frame area (from recent NRC contract work by S. Carpenter of Enermodal for NRC.)

When the marginal solar utilizability drops below 0.7 then the wall actually becomes a better energy performer than the window. From Figure 21 it is seen that the window area is still modest when this point is reached in a typical wood-frame house. An optimum window area for energy savings is well within what is usually desired for lighting and lifestyle.

Obviously little progress can be made in passive solar if there is not significant improvement in window technology. This applies to windows for commercial as well as residential buildings even though triple-glazed windows have already been seen to be cost-effective in certain cases like condominiums. The small market for the superior windows now available and the technology used in them have kept their additional costs at levels that deter buyers. However, breakthroughs are now occurring in the United States, creating a rapidly expanding market for low-emissivity double-pane units. Canada has a climate that makes it even more logical to move in this direction.

4.3.2 Economic Potential for Passive Solar in Canada

To assess the potential of advanced window concepts the energy performance of a number of options are shown in Figure 22. In Figure 23 the cost premium that can be justified over a double-glazed unit has been calculated by averaging the performance gain over south and north orientations and multiplying by the cost-effective threshold level of 120 $/(GJ·a^{-1})$. Given these cost targets most of these options look eminently feasible. This is all the more understandable when one realizes that the present cost for the sealed double glazings represents only 15-20% of the total cost of the

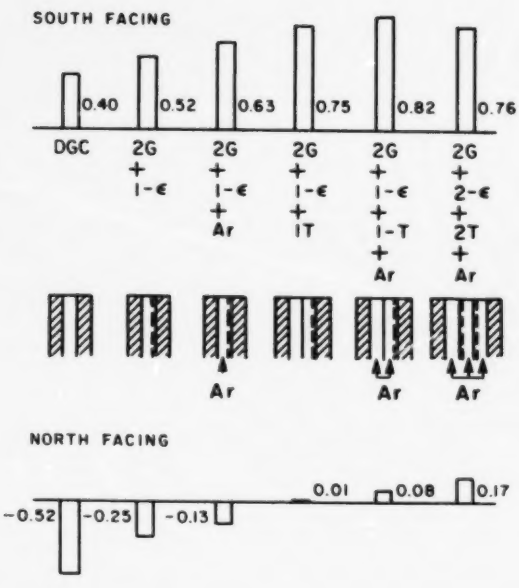


Figure 22. Net energy balance through different glazing options in Ottawa. (This is a new work based on the VISION program of J.L. Wright and a methodology proposed in S.J. Harrison and S.A. Barakat, "A Method for Comparing the Thermal Performance of Windows," ASHRAE Trans. 89(1A): 3-11; 1983.)

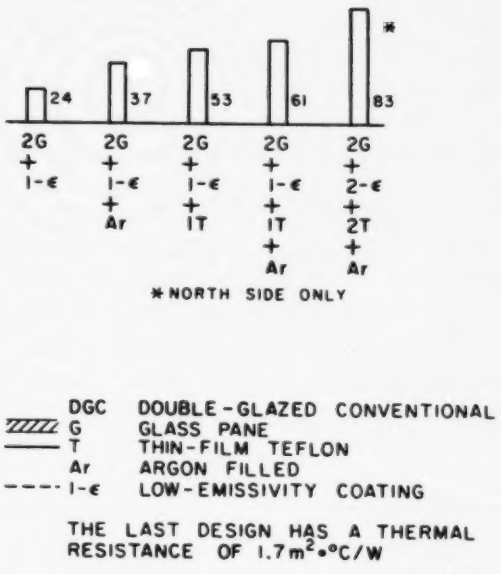


Figure 23. Justifiable cost premium for different glazing options in Ottawa

conventional window. With the huge expenditures now being on the sash and frame it also appears eminently feasible to improve the performance on these components cost-effectively. In brief, this is a very promising field of development.

Super windows will be popular with the individual homeowner because they allow new flexibility in house design with attractive, light areas added and no energy penalties. The windows will allow new, more healthy levels of humidity to be maintained in winter with no condensation build-up on the windows. For commercial buildings, a key advantage of super windows is that expensive perimeter heating systems are not needed and that buildings can be designed with the popular "all-glass look" without incurring an energy penalty.

The impact of the new windows on the energy situation in Canada will also be very positive. By reinforcing the weakest link in the perimeter thermal resistance of a building the overall energy load and the peak load are

reduced substantially (see Figure 24). Thus, the windows have a high capacity credit, i.e., not only is fuel consumption reduced but the actual capacity to generate energy can be reduced (or more correctly in the Canadian context, existing electricity capacity can be used more effectively). The new windows also make other load management economical and practical. For instance, it becomes much simpler to have a combined hot water tank and storage unit that allows all the space heating requirements to be met by off-peak electricity at night. Some of the most recent total strategies for improved energy management in a house include ventilation windows with heat recovery, central air exhaust with heat pump recovery for the hot water supply, and a radiant heating system to reduce total heat loss but retain comfort and a good fresh air supply.

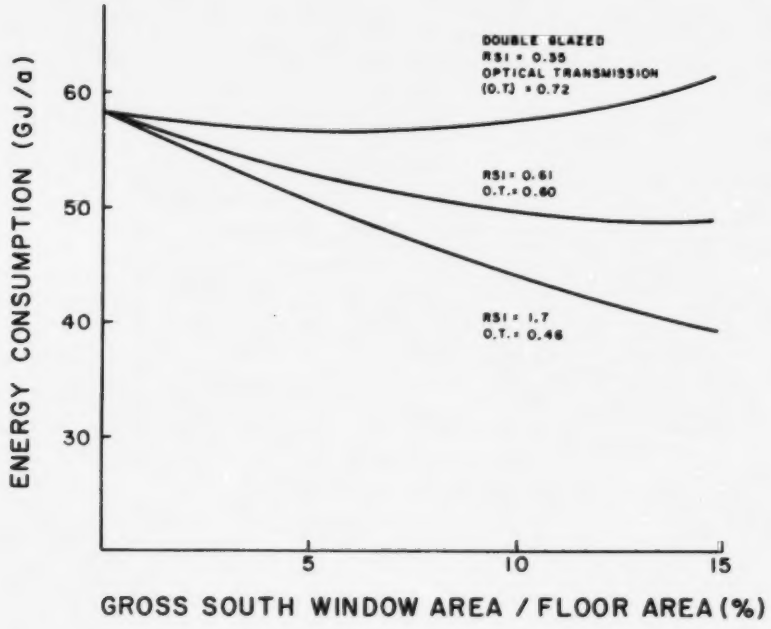


Figure 24. Effect of south window thermal resistance on building energy consumption (from recent NRC contract work by S. Carpenter of Enermodal for NRC).

5. PHOTOVOLTAICS

5.1 International Perspective of Photovoltaics

Photovoltaic (PV) technology directly converts solar radiation into electricity. Because the energy output is high grade and versatile it is the most attractive of the solar energy options as a long term replacement for the fossil fuels. Present applications include powering communication relays, monitoring equipment, navigational aids, and other remote-site equipment where the solar cost effectiveness is gained not through direct competition with the cost of conventional fuels but with the cost of transport of the fuel to the site. Another large market area now is in powering calculators, wrist watches, and the like. This is especially important to the Japanese industry.

The photovoltaic market has been increasing exponentially since 1974 as the prices have been lowered some 10-fold (Figures 25 and 26). The PV market should continue to expand, but with reduced relative increases from year to year. Newer markets, like remote lighting, cathode protection, and water pumping, are expected to replace some of the saturating ones as module prices drop from about 8 $\$/W_p$ now to 3-4 $\$/W_p$ by 1990.[2]

In pumping applications and even more so for village power, direct competition with diesel power units becomes increasingly important. The competitiveness of photovoltaic systems will depend not only on the reduced price of PV cells but on cost reductions in batteries, inverters, and regulators as well as the evolution of world oil prices.

The ultimate market of grid-connected solar cells depends on cost reductions in the solar cells, in the balance-of-system components, and in improvements in cell efficiencies. The American goals for cost effectiveness in the late 1990's for this application are given in Table 2. These goals would lead to a life-cycle cost of 0.065 \$/kWh (1982 constant U.S. \$).

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[2]The power output of a solar cell module under ideal conditions, maximum solar radiation at normal incidence, is given in peak Watts Wp. As the maximum solar radiation is considered as 1 kW/m^2, a 8 $\$/W_p$ module price with 10% efficiency would be 800 $\$/m^2$. The average output over a long period is some 6 to 10 times less than this maximum, depending on the climate. Thus, to provide a continuous power of 1 W the solar cells at 8 $\$/W_p$ would cost approximately \$64. The batteries and other equipment such as a voltage regulator would be supplementary. The cost to power a 20-W navigational light with solar cells would be $(8W_p/W_{cont})(8\ \$/W_p)(20W_{cont})$ = \$1280 plus battery and regulator costs. To power the system if grid electricity were available at 0.10 \$/kWh would cost annually:

$$(0.10\ \$/kWh)((0.02kW)(24h/d)(365d/a)=17.52\ \$/a.$$

Typically, grid extension is costly or impractical for good photovoltaic applications now.

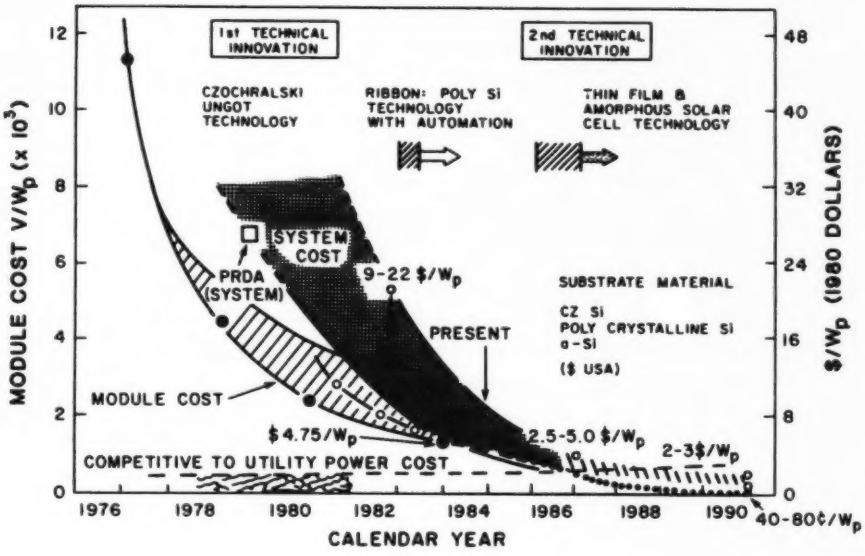

Figure 25. Evolution of photovoltaic module costs (after a figure in Y. Hamakawa, "Recent Advances in Amorphous Silicon Solar Cells and their Technologies," Proceedings of Intersol '85, June 1985).

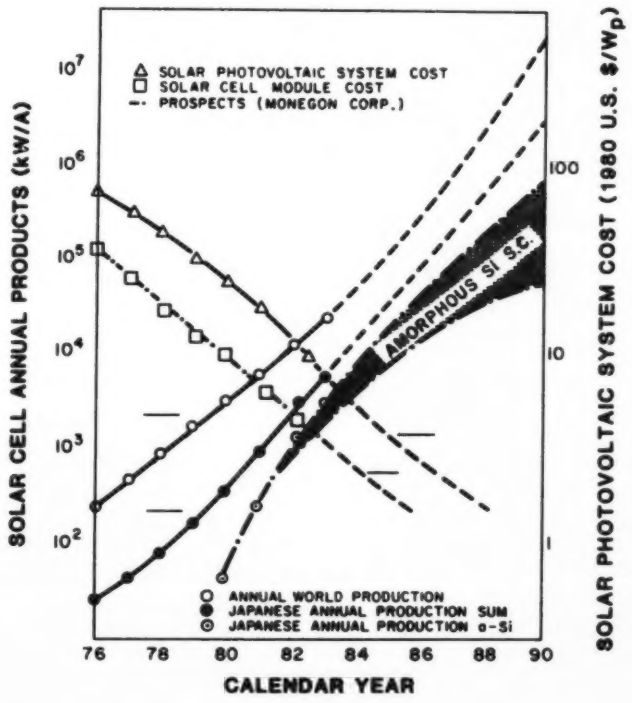

Figure 26. Evolution of the production of photovoltaic modules (after a figure in Y. Hamakawa, "Recent Advances in Amorphous Silicon Solar Cells and their Technologies" Proceedings of Intersol '85, June 1985).

Table 2. U.S. federal/industry long-term technical goals
(1982 U.S. $)

	Systems			
	Flat-plate		Concentrator	
Module efficiency	13-17%	0.4$/$W_p$	23-29%	0.5$/$W_p$
Module cost	40-75 $/m^2		90-160 $/m^2	
Balance-of-system costs				
Area related	50 $/m^2		100 $/m^2	
Power related	150 $/kW		150 $/kW	
System life expectancy	30 years		30 years	

These cost goals are extremely challenging. The present thick-film technologies using highly purified crystalline silicon are understood to be limited by the high cost of their materials. Research into thin-film and multijunction concepts has the most potential for meeting the long-term goals. However, much of the progress needed is still at the fundamental research level. For example, one of the accomplishments of the last year was a clearer understanding of the light-induced degradation of amorphous silicon passivated with hydrogen. Solving of this durability problem associated with amorphous silicon is critical to the further development of this particular technology path. The most recent reports indicate that high durability has been achieved in a triple-stack thin-film cell of fluorinated amorphous silicon.

Photovoltaic research is costly and risky and the high level of government support in the United States, Japan, and Europe is critical to maintaining the momentum. Many paths to success (and to failure) are still open. Important advances in one sector may render obsolete another technology that has just been developed at great expense. While all the programs have strong private sector participation the governments support directly a portion of R&D funding and ensure good evaluation of work and exchange of information. The Japanese government budget for photovoltaics (heavily concentrated on amorphous silicon research) was about $44,000,000 in 1984 while that of the United States was some $45,000,000. The current American research plan of 1984-88 strongly emphasizes the high-risk, longer-term research as opposed to the earlier strategy that had a larger component of very substantial demonstration projects.

5.2 Canadian Accomplishments in Photovoltaics

Through contracts with NRC some of the small Canadian companies were able to make contributions to the international efforts in increasing the efficiency and reducing the costs of the solar cells. One company investigated the production of large area cells on both monocrystalline and polycrystalline silicon substrates using the technique of spray pyrolysis to deposit transparent conduction oxide layers. The cell manufacturing process

developed was inherently cheaper than the standard ones used at the time. It involved far fewer processing steps. The active junction was formed with the spray-on oxide coatings and the electrical contacts were screen-printed. Average efficiencies of 14% were reported in a paper presented at the 17th IEEE Photovoltaic Specialist Conference in May 1984.

Another Canadian company reported at this same conference progress in using a method of fabricating low-cost solar-cell grade substrates directly from metallurgical grade silicon. A fast three-step leaching process was used to upgrade this silicon. The refined powder was then spread on a reusable graphite substrate and subjected to two scans with an electron beam to produce a smooth flat polycrystalline substrate.

The same company has had some success in assembling photovoltaic modules using techniques requiring a fair level of manpower but small capital investment. In countries with low wages this is an attractive combination and sales of complete assembly lines have been made to India and China.

Research is on-going at a number of universities to solve some of the problems associated with the degradation of amorphous silicon. There have been no major breakthroughs yet but the quality of the work already performed indicates that Canada can make significant scientific contributions in the field.

One example of a successful project to develop a total system that would work well with photovoltaic power was that using a special reverse osmosis desalination process perfected in Canada. The energy recovery pumps of the system maintain very high efficiency over a wide range of input power as opposed to conventional units that work much better at fixed voltage and current. The Canadian unit is thus particularly well suited to operation with solar cells. The results from experiments with the prototype confirmed the very high efficiency possible with this system configuration. Analysis also showed that the combination of energy recovery features and photovoltaic power was superior from an economic viewpoint to more conventional PV-powered desalination units.

The recent focus of NRC in-house research was aimed at providing much better information to designers and installers on how to optimize PV systems for performance in the Canadian climate. A PV systems experimental facility was just to be built when the closure of the program was announced. However, some work had already begun on simulation of PV systems. The TRNSYS package was taken as a starting point for detailed hour-by-hour simulation work. A new sub-routine was developed to model a PV module or array to predict current and voltage output based on meteorological data in the format given by the Atmospheric Environment Service. Other sub-routines were developed to give total systems performance for water pumping applications.

The National Solar Test Facility (NSTF) has recently acquired new capabilities in testing photovoltaic modules. With only a few minor exceptions the NSTF can test modules to (a) the Canadian Coast Guard Specification MA 2055, (b) the Canadian Standards Association standard on PV modules F380, and (c) the JPL Test Specification 5101-161. As part of a total program to develop and evaluate photovoltaic-powered pumping systems, new facilities to test these systems have been built at NSTF. Equipment includes a 60-m borehole, a power supply, a test control and data acquisition system, and a computer modelling program.

5.3 The Economics of Photovoltaics

It is obvious from the footnote of Section 5.1 that photovoltaics is not about to compete with grid electrical operating costs in the near or medium term. But solar cells are finding cost effective applications and the first was in the displacement of primary battery power supply at remote sites. The power can be for navigational aids, monitoring and sensing devices, or VHF repeater stations. The PV system can reduce the number of helicopter visits from once every two weeks to once a year (a helicopter rents for about 400 $/h) or it can reduce the necessary battery storage from 1 a to 10-20 d. The Canadian Coast Guard and Environment Canada among others are making large scale conversions of primary battery to photovoltaic systems.

Photovoltaic systems can also be competitive in remote applications where external combustion generators are now used. The latter are reliable but inefficient in heat-to-electricity conversion. Thermo-electric generators and closed-cycle vapor turbines have efficiencies of about 3% while the recently-introduced thermo-mechanical generators achieve 9%. The high initial investment (for a 100-W continuous load it would cost about $6000 to buy a TEG and $20 000 to $30 000 for either of the other two generators) plus the fuel requirements make these options costly and a target for displacement by photovoltaics. Photovoltaic market penetration in this sector is more dependent on having optimized and very reliable PV systems (including batteries) than on further substantial reductions in module costs.

Gasoline and propane internal combustion generators have efficiencies of about 10% and are considerably less costly to buy than the external generators. However, they require regular maintenance at 100- to 200-h intervals. They are most valuable in responding to intermittent loads. Photovoltaic systems are not cost competitive with these systems from a simple standpoint of displacement of fuel costs. One of the first applications that will become cost effective for photovoltaic cells displacing gasoline units is water pumping, but even for this it will require 3 $/$W_p$ PV modules and optimized systems. Third-world countries offer the best prospects for significant medium-term market for solar cells to displace gasoline

internal combustion units because the potential low maintenance requirement for the PV system will be a major advantage there.

A combination of PV and the internal combustion generators can be effective in Canada where high reliability is sought and the usage is fairly continuous, making the maintenance of a stand-alone generator onerous. This occurs, for example, in powering houses or cottages far from the electrical grid. Sales have been made of a combination of a 280-W_p array, a 2.2-V, 480-Ah battery system, a charge regulator, and a 1200-W inverter for about $7300. A generator is used in conjunction with this PV system occasionally for heavy loads and to equalize charge on the batteries, and to reduce the required array size for winter operation.

Grid extensions are in the range of $10 000 to $20 000 per kilometre. It takes a combination of very low load, e.g., for lighting, and remoteness to make photovoltaics competitive. A recent prototype development indicated the cost of a PV power package for a 53-W lighting system would be $12 500 of which $5000 would be for the PV modules alone. Even for this very small load the site would have to be a few kilometres from grid for photovoltaics to be economic.

For larger loads (1 to 500 kW) and remote locations the competition for photovoltaics is in diesel-powered internal combustion generators. Efficiencies of 25% can be achieved if there is a good match been the load and power output capability of the unit. In a strict fuel displacement mode solar cells are not likely to be cost effective in the medium term. Some poorly adapted diesel systems produce as little as 1.6 kWh/L but more common now are systems giving 2 to 2.8 kWh/L. Fuel costs in remote villages vary typically from 0.30 $/L to 0.70 $/L and only very rarely are greater than 1 $/L. With solar cells producing about 1.1 kWh/W_p annually, PV system costs would have to drop below 3 $/Wp to be competitive based on fuel savings alone.

The real opportunity for photovoltaics is in reducing the maintenance and operating costs for the smaller systems. In larger systems there are usually a series of units of different sizes so that they be combined to match the power output to the load. The operating costs can be amortized over a large base and economies of scale are realized in the use of manpower.

The most recent advance in load management for small systems is the use of a charge cycling regime whereby the diesel unit works at full capacity to supply load and gradually charge up a 6-9 h supply of electricity in battery storage. Then the diesel unit can shut off for a few hours with supply coming from the batteries. With a certain level of depletion of the batteries the diesel unit starts up and works at full capacity again. The batteries are a very expensive part of this total system but cost

competitiveness has been attained with it, especially with the improved maintenance record. This offers an opportunity for photovoltaics in that the already-available batteries and cycle regime make the energy of solar cells fully utilizable. If the reliability through the combination of photovoltaics plus cycle charge can reduce operating and maintenance in a very significant manner, for instance, in reducing the necessary surveillance from full time to the occasional visit, then photovoltaics may be justified.

It is unlikely that solar cells in a stand-alone mode will displace the diesel units themselves in Canada. Current costs heavily favor the diesel and often the heat from the generators is needed in winter. However, in third world applications there should be gradual introduction of the self-standing 1-5 kW photovoltaic systems because of the advantages in reliability.

6. CONCLUSIONS

Over the next 20 to 30 years it is the passive element of the solar R&D program that will have the largest impact on energy demand in Canada. This is not passive solar understood in the narrow sense of putting additional windows into a building to increase the solar gain. Rather it involves having the same window area as typically used now but orienting a majority of it towards the south and using superior technology to reduce heat loss from the windows. From the figures presented earlier it can be deduced that improvements of 10-15 GJ/a in the energy performance of a house can be achieved through proper orientation of the windows and an added 10 GJ/a through the new window technology.

With new housing starts projected to be in the range of 120,000 to 160,000 per year over the next 15 years, energy consumption can be reduced 3 PJ/a for each year in which the new techniques are widely employed. A very substantial market for the new windows also lies in the retrofitting of older houses. Each year approximately the same number of house retrofits of windows as of new housing starts can save another 1-2 PJ/a. Depending on the rate of penetration of the new concepts the overall effect by the year 2000 will be between 100 to 200 PJ of energy savings.

The degree of success achieved to date in the development of innovative window technology owes much to the NRC program providing coordination, information transfer, and evaluation. This infrastructure has allowed expertise in universities, research centres, and small innovative companies to direct research efforts to the areas with most potential for industrial and economic benefits. Support from this pool of expertise remains essential to the success of the program because the Canadian window industry is too fragmented and its R&D capabilities too limited to undertake itself the necessary research. With much remaining to be done in window research it is important to continue a directed program of coordination and evaluation if the economic and energy potential of super window development is to be realized in Canada.

Canada's active solar industry has made great progress over the last 7 years and now is in a position to compete internationally with its products. However, this report has pointed out numerous areas where the technology can be expected to progress even more in the near term. The industry will need to maintain its R&D activities to remain competitive and develop more fully its export trade. Active solar technology should not be expected to contribute in any significant way to Canada's energy supply through the medium term but it can realistically be expected to generate some industrial benefits.

To encourage a more economic and rational exploitation of the PV technology the NRC's R&D program group had recently decided to focus on developing an

expertise in optimization of systems. The communication and power companies and government agencies like the Canadian Coast Guard are exploiting photovoltaic technology in good applications but the progress has been slower than needed because of the lack of coordination between different groups. A coordinated program for systems testing and analysis still appears as one of the most logical contributions the government can make to promoting PV development and keeping Canada in a position to profit from this attractive long-term energy option.

7. A GUIDE TO FURTHER INFORMATION

Among the many journals dealing with issues of solar energy one which provides pragmatic overviews for laymen and solar businessmen is Solar Age, published monthly by SolarVision. Solar Energy, the Journal of Solar Energy Science and Technology is the monthly publication of the International Solar Energy Society. The articles are on diverse research endeavours from around the world. Solar Energy Materials, and Solar Cells are for the research specialists in their respective fields.

A few publications specialize in providing up-to-date briefings. They include:

- Solar Energy Intelligence Report, published weekly by L.A. Eiserer
- Photovoltaic News, editor Paul Maycock
- Photovoltaic Insider's Report

The proceedings of the many solar conferences are a good source of information. Some of these conferences are:

- Biennial Conference of the International Solar Energy Society. The latest was Intersol 85 held in Montreal, June 1985.
- American Society of Mechanical Engineers Solar Energy Division Annual Conference. The proceedings are entitled Solar Engineering-198_.
- American Solar Energy Society Annual Meeting.
- Solar Thermal Research Program Annual Conference sponsored by the U.S. Department of Energy and the Solar Energy Research Institute.
- American Solar Energy Society Annual Passive Solar Conference. The report is entitled ASES Proceedings of the _th Passive Solar Conference.
- IEEE Photovoltaic Specialists Conference.
- Photovoltaics Advanced Research and Development Review Meeting, sponsored by the U.S. Department of Energy and the Solar Energy Research Institute.
- Symposium on Materials and New Processing Technologies for Photovoltaics sponsored by the Electrochemical Society.

Canadian sources of information include:

- SOL, a magazine published six times a year by the Solar Energy Society of Canada Inc. The Solar Energy Development Program of EMR has chosen this publication as the vehicle for transmitting much of the information on its activities.

- Solar Energy Program Contract Registry. The 1984-86 registry will be the last published by the National Research Council but a similar report will be issued in the future by EMR.
- Solplan Review, published six times a year by The Drawing-Room Graphic Services Ltd. This magazine emphasizes information on energy-efficient construction and offers a regular column by LEBCO, the Low Energy Building Council.
- Proceedings of the Annual National Conference of the Solar Energy Society of Canada. The 1985 conference was held in conjunction with ISES under the name of Intersol 85. The preceding conference was SESCI '84 Calgary.

7.1 The Solar Resource

Canadian solar radiation data are available for 129 sites across the country in printed tables or stored on nine-track magnetic tape or floppy disks. The stored data also includes hourly values of air temperature, humidity, wind speed and direction. Information on this data, its procurement and cost, can be obtained from:

Climatological Services Division
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario
M3H 5T4

contact: Mike Webb (416) 667 4953 for the tapes
Bernie Yorke (416) 667 4614 for the tables

The principal books available are:

- Solar Radiation Data Analyses for Canada, 1967-76
  - Volume 1. The Atlantic Provinces ($30)
  - Volume 2. Quebec ($24)
  - Volume 3. Ontario ($30)
  - Volume 4. The Prairie Provinces ($36)
  - Volume 5. British Columbia ($30)
  - Volume 6. The Yukon and the North West Territories ($18)

An overview of the methodology of solar measurements is in a report prepared for Task IV of the Solar Heating and Cooling Programme of the IEA. It is titled:

- An Introduction to Meteorological Measurements and Data Handling for Solar Energy Applications, for Solar Energy Applications, October 1980, DOE/ER-0084.

A few reports and research articles that are in themselves overviews are by:

- Davies, J.A., 1981: Models for Estimating Incoming Solar Irradiance. Canadian Climate Centre Report No. 81-2, Atmospheric Environment Service, Downsview, Ont.
- Siurna, D.S., D'Andrea, L.J., and Hollands, K.G.T., 1984: A Canadian Representative Meteorological Year for Solar System Simulation. SESCI '84 Calgary Proceedings, pp 85-88.
- Hay, J.E., and McKay, D.C., 1985: Estimating Solar Irradiance on Inclined Surfaces: A Review and Assessment of Methodologies. Solar Energy, 3 (4-5), pp. 203-240.

John Hay is also preparing a monograph for the Atmospheric Environment Service on the Solar Radiation Climate of Canada. This should be available in the latter part of 1986.

7.2 Active Solar Technology

Many of the good references on active solar technology can be assessed through the Contract Registry and the other publications mentioned earlier. One document that served in providing some of the international material for this report was by:

- Hardacre, A.G., Blum, S.B., and Torrenti, R., 1984: Solar Energy Research Outside Sweden, Sweden Council for Building Research Document D22:1984.

A few Canadian addresses that could be useful in pursuing questions on active solar technology are:

Solar Energy Development Program
Energy, Mines and Resources Canada
460 O'Connor Street, Room 426
Ottawa, Ontario
K1A 0E4 (613) 995 9447

Canadian Solar Industries Association Inc.
67A Sparks Street
Ottawa, Ontario
K1P 5A5 (613) 237 7000

For information and use of the solar simulation program WATSUN one should contact:

WATSUN User Service
University of Waterloo
Waterloo, Ontario
N2L 3G1 (519) 885 6160

7.3 Passive Solar Technology

Among a number of publications by the Institute for Research in Construction (IRC) of NRC three are cited here that allow one to estimate the solar gains in a simple direct-gain passive house.

- Barakat, S.A., and Sander, D.M., 1982: Utilization of Solar Gains Through Windows for Heating Houses, Building Research Note 184.
- Barakat, S.A., and Sander, D.M., 1982: A Simple Method for Determining the Heating Requirements of Direct-Gain Passive Solar Houses, Building Research Note 195.
- Barakat, S.A., 1980: Solar Heat Gains Through Windows in Canada, DBR Paper No. 944, NRCC 18674.
  (In applying the window heat-gain data from the last reference to the other two papers it is important to note that the data are based on the glazing area only. To account for the effect of the window frame, its area can be subtracted from the total window area to give the net glazing area. Then from the glazing heat gain (or loss) should be subtracted the additional heat loss of the window frame, see Figure 21 of this report.)

The HOTCAN energy analysis program developed by IRC is now being offered by:

Energy Analysis Software
P.O. Box 7081
Postal Station J
Ottawa, Ontario
K2A 3Z6 (613) 722 5091

HOT-2000, an enhanced version of HOTCAN, is expected to be available in October.

ENERPASS, a simulation program that can analyze a passive solar home's energy performance is available from:

Enermodal Engineering Limited
368 Phillip Street, Unit 2
Waterloo, Ontario
N2L 5J1 (519) 884 6421

The following address is not only home to SESCI, but also to LEBCO, the Low-Energy Building Corporation.

SESCI
Suite 206 - 135 York Street
Ottawa, Ontario
K1N 5T4 (613) 236 4594

The EMR address given previously is also relevant to the continuing passive program.

Two publications that served in this report to analyze window performance are:

- Harrison, S.J., and Barakat, S.A., 1983: A method for Comparing the Thermal Performance of Windows, ASHRAE Trans. 89(1A): 3-11.

- Wright, J.L., and Ferguson, J.E., 1984: VISION: A computer program to evaluate the thermal performance of super windows. Passive-10, Solar Energy Program, NRC.

7.4 Photovoltaic Technology

Many of the developments in the American program can be followed through the update reports to the five-year plan announced in 1983. The original document was:

- Five Year Research Plan, 1984-1988, Photovoltaics: Electricity from Sunlight, by the Photovoltaic Energy Technology Division, Office of Solar Electric Technologies, U.S. Department of Energy, DOE/CE-0072.

More recent documents from this program can be found in the NTIS data base.

The Canadian situation can be appraised in the following:

- Assessment of the Canadian Market for Photovoltaic Power System, by the Techno-Economic Research Unit Limited, Ontario Ministry of Energy, 1984.
- Overview and Assessment of Photovoltaic Technical, Industry and Market Development Opportunities, by Spectral Engineering Ltd. et al. Ontario Ministry of Energy, 1983.
- Photovoltaic Technology Overview, by Spectral Engineering Ltd. Solar Energy Program, NRC, 1986 (available on loan from CISTI).

A review of the operations of the Photovoltaics Sub-Program of the Solar Energy Program from its beginning to end is presented in:

- SEP Photovoltaics Program Review, by the Photovoltaic Sub-Program, SEP, NRC, 1985. This document is available on loan from CISTI.

Further information on the ongoing Canadian government photovoltaics program can be obtained from the Solar Energy Development Program of EMR.